IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

SAMSUNG ELECTRONICS, CO. LTD., Plaintiff, v. SHARP CORPORATION, SHARP ELECTRONICS CORPORATION, and SHARP ELECTRONICS MANUFACTURING COMPANY OF AMERICA, INC., Defendants.	C.A. No. 07-843-SLR **DEMAND FOR JURY TRIAL**
SHARP CORPORATION, SHARP ELECTRONICS CORPORATION AND SHARP ELECTRONICS MANUFACTURING COMPANY OF AMERICA, INC., Counterclaim-plaintiffs, v. SAMSUNG ELECTRONICS, CO. LTD., SAMSUNG ELECTRONICS AMERICA, INC., and SAMSUNG SEMICONDUCTOR, INC., Counterclaim-defendants.	

ANSWER AND COUNTERCLAIMS OF DEFENDANTS SHARP CORPORATION, SHARP ELECTRONICS CORPORATION, AND SHARP ELECTRONICS MANUFACTURING COMPANY

Defendants Sharp Corporation ("Sharp"), Sharp Electronics Corporation ("SEC"), and Sharp Electronics Manufacturing Company of America, ("SEMA"), by and through the undersigned counsel, hereby respond and counterclaim to the Complaint of Plaintiff Samsung Electronics, Co., Ltd. ("Samsung"), and assert claims for infringement against as follows:

ANSWER TO SAMSUNG'S COMPLAINT

THE PARTIES

1. Sharp, SEC and SEMA (the "Sharp Parties") admit the allegations of paragraph 1 on information and belief.

2. The Sharp Parties admit the allegations of paragraph 2.

3. The Sharp Parties admit the allegations of paragraph 3.

4. The Sharp Parties admit the allegations of paragraph 4.

JURISDICTION AND VENUE

5. The Sharp Parties admit the allegations of paragraph 5.

6. The Sharp Parties do not contest that that this Court has personal jurisdiction over them for this action. Except as specifically admitted, the Sharp Parties deny the allegations of paragraph 6.

7. The Sharp Parties do not contest that that this Court has personal jurisdiction over them and that venue is proper in this District for this action. Except as specifically admitted, the Sharp Parties deny the allegations of paragraph 7.

COUNT ONE

8. The Sharp Parties incorporate by reference their responses to the allegations of paragraphs 1 through 7 of Samsung's Complaint.

9. The Sharp Parties admit that Exhibit 1 appears to be a copy of U.S. Patent No. 7,193,666 ("the '666 patent"), and that the '666 patent is entitled "Dual Liquid Crystal Display Device" and states on its face that it issued on March 20, 2007, and that Samsung is the assignee of record. The Sharp Parties are without knowledge or information sufficient to form a belief as to the remaining allegations in paragraph 9, and therefore deny the same.

10. The Sharp Parties deny the allegations of paragraph 10.

11. The Sharp Parties deny the allegations of paragraph 11.

12. The Sharp Parties deny the allegations of paragraph 12.

COUNT TWO

13. The Sharp Parties incorporate by reference their responses to the allegations of paragraphs 1 through 12 of Samsung's Complaint.

14. The Sharp Parties admit that Exhibit 2 appears to be a copy of U.S. Patent No. 6,771,344 ("the '344 patent"), and that the '344 patent is entitled "Liquid Crystal Display Having Wide Viewing Angle" and states on its face that it issued on August 3, 2004, and that Samsung is the assignee of record. The Sharp Parties are without knowledge or information sufficient to form a belief as to the remaining allegations in paragraph 14, and therefore deny the same.

15. The Sharp Parties deny the allegations of paragraph 15.

16. The Sharp Parties deny the allegations of paragraph 16.

17. The Sharp Parties deny the allegations of paragraph 17.

COUNT THREE

18. The Sharp Parties incorporate by reference their responses to the allegations of paragraphs 1 through 17 of Samsung's Complaint.

19. The Sharp Parties admit that Exhibit 3 appears to be a copy of U.S. Patent No. 7,295,196 ("the '196 patent"), and that the '196 patent is entitled "Liquid Crystal Display Panel With Signal Transmission Patterns" and states on its face that it issued on November 13, 2007, and that Samsung is the assignee of record. The Sharp Parties are without knowledge or

information sufficient to form a belief as to the remaining allegations in paragraph 19, and therefore deny the same.

20. The Sharp Parties deny the allegations of paragraph 20.

21. The Sharp Parties deny the allegations of paragraph 21.

22. The Sharp Parties deny the allegations of paragraph 22.

COUNT FOUR

23. The Sharp Parties incorporate by reference their responses to the allegations of paragraph 1 through 22 of Samsung's Complaint.

24. The Sharp Parties admit that Exhibit 4 appears to be a copy of U.S. Patent No. 6,937,311 (the "'311 patent"), and that the '311 patent is entitled "Liquid Crystal Display Having Domain Dividers" and states on its face that it issued on August 30, 2005, and that Samsung is the assignee of record. The Sharp Parties are without knowledge or information sufficient to form a belief as to the remaining allegations in paragraph 24, and therefore deny the same.

25. The Sharp Parties deny the allegations of paragraph 25.

26. The Sharp Parties deny the allegations of paragraph 26.

27. The Sharp Parties deny the allegations of paragraph 27.

FIRST AFFIRMATIVE DEFENSE

28. The Sharp Parties did not, and do not, directly or indirectly infringe, or contribute to or induce the infringement of any valid and enforceable claim of the '196, '666, '311, or '344 patents, and have not otherwise committed any act in violation of 35 U.S.C. § 271.

SECOND AFFIRMATIVE DEFENSE

29. On information and belief, the claims of the ‘196, ‘666, ‘311, and ‘344 patents are invalid because they fail to comply with the statutory requirements of patentability specified in 35 U.S.C. §§ 102, 103, 112, and/or 116.

THIRD AFFIRMATIVE DEFENSE

30. The relief sought by Samsung is barred in whole or in part by the doctrine of laches.

FOURTH AFFIRMATIVE DEFENSE

31. Samsung’s remedies are limited due to failure to mark its products as required by 35 U.S.C. § 287.

FIFTH AFFIRMATIVE DEFENSE

32. To the extent Samsung accuses any product or process of the Sharp Parties that is incorporated into the product or process of a Samsung licensee, Samsung’s claims are barred under the doctrine of patent exhaustion.

SIXTH AFFIRMATIVE DEFENSE

33. Samsung’s claims are barred by the doctrine of unclean hands.

SEVENTH AFFIRMATIVE DEFENSE

34. The Sharp Parties reserve the right to assert any other defenses that discovery may reveal, including the defense of unenforceability due to inequitable conduct.

COUNTERCLAIMS AND THIRD PARTY CLAIMS

Counterclaim-plaintiffs SEC, SEMA, and Sharp allege as follows:

PARTIES

35. Sharp Corporation is a corporation organized under the laws of Japan, with its principal place of business at 22-22 Nagaike-cho, Abeno-ku, Osaka 545-8522, Japan. Sharp is a leading innovator and manufacturer of liquid crystal display modules ("LCD Modules") as well as television sets and computer monitors that incorporate LCD Modules ("LCD Products").

36. Sharp Electronics Corporation ("SEC") is a corporation organized and existing under the laws of New York, with its principal place of business at 1 Sharp Plaza, Mahwah, New Jersey 07340-2135.

37. Sharp Electronics Manufacturing Company of America, Inc. ("SEMA") is a corporation organized under the laws of California, with its principal place of business at 9295 Siempre Viva Road, Suite J2, San Diego, California 92154.

38. Counterclaim defendant Samsung Electronics Co., Ltd. ("Samsung") is a limited liability corporation organized under the laws of Korea, with its principal place of business at 250, Taepyeongno 2-ga, Jung-gu, Seoul, 100-742, Korea. Samsung manufactures LCD Modules and directs those products to the United States, including the District of Delaware, through established distribution channels involving various third parties, knowing that these third parties will use their respective nationwide contacts and distribution channels to import into, sell, offer for sale, and/or use these LCD Modules and LCD Products incorporating such LCD Modules in the District of Delaware and elsewhere in the United States.

39. On information and belief, counterclaim defendant Samsung Electronics America, Inc., ("SEA") is a corporation organized under the laws of New York, with a principal place of business at 105 Challenger Road, Ridgefield Park, New Jersey 07660. On information and belief, SEA is a direct or indirect subsidiary of Samsung and either directly or indirectly imports into, sells, and/or offers for sale LCD Products in the United States, including in the District of Delaware.

40. On information and belief, counterclaim defendant Samsung Semiconductor, Inc. ("SSI") is a corporation organized under the laws of California, with a principal place of business at 3655 North First Street, San Jose, California 95134. On information and belief, SSI is a direct or indirect subsidiary of Samsung and either directly or indirectly imports into, sells, and/or offers for sale LCD Products in the United States, including in the District of Delaware.

41. On information and belief, Samsung, SEA and SSI are affiliated entities engaged in making, offering for sale, selling and/or using, in the United States of America and elsewhere, LCD Modules and LCD Products, and are further engaged in importing LCD Modules and LCD Products into the United States of America, and otherwise making such products available in the United States of America. On information and belief, Samsung directly or indirectly controls SEA and SSI, SEA and SSI are the agents of Samsung, and Samsung is liable for the activities of SEA and SSI.

JURISDICTION

43. This Court has subject matter jurisdiction over this action pursuant to 28 U.S.C §§ 1331 and 1338(a) because the action concerns a federal question relating to patents arising under Title 35 of the United States Code, and pursuant to 28 U.S.C. §§ 2201 and 2202.

VENUE

44. Venue in the District of Delaware is proper pursuant to 28 U.S.C. §§ 1391(b), (c) and (d) and 1400(b), because Samsung is an alien and has consented to the jurisdiction and venue of this Court, because SEA and SSI are authorized to do business and are doing business in the State of Delaware, including this District, and have committed acts of infringement in this District; and because SEA and SSI are each subject to personal jurisdiction of this Court.

FIRST DECLARATORY JUDGMENT COUNTERCLAIM

45. The Sharp Parties assert this counterclaim against Samsung.

46. The Sharp Parties incorporate by reference the allegations of paragraphs 1-44 hereof as though the same were set forth fully herein.

47. The Sharp Parties did not and do not directly infringe, indirectly infringe, contribute to or induce the infringement of any valid and enforceable claim of the ‘589 patent, and have not otherwise committed any acts in violation of 35 U.S.C. § 271.

48. The ‘589 patent is invalid and/or unenforceable for failing to meet the conditions of patentability set forth in 35 U.S.C. §§ 102, 103, 112, and/or 116.

49. An actual controversy exists between Samsung and the Sharp Parties concerning the alleged infringement, validity, and/or enforceability of the ‘589 patent by virtue of Samsung’s claim for infringement in this suit.

50. The Sharp Parties are entitled to judgment from this Court that the ‘589 patent is not infringed by the Sharp Parties, and is invalid and/or unenforceable.

SECOND DECLARATORY JUDGMENT COUNTERCLAIM

51. The Sharp Parties assert this counterclaim against Samsung.

52. The Sharp Parties incorporate by reference the allegations of paragraphs 1-44 hereof as though the same were set forth fully herein.

53. The Sharp Parties did not and do not directly infringe, indirectly infringe, contribute to or induce the infringement of any valid and enforceable claim of the '177 patent, and have not otherwise committed any acts in violation of 35 U.S.C. § 271.

54. The '177 patent is invalid and/or unenforceable for failing to meet the conditions of patentability set forth in 35 U.S.C. §§ 102, 103, 112, and/or 116.

55. An actual controversy exists between Samsung and the Sharp Parties concerning the alleged infringement, validity, and/or enforceability of the '177 patent by virtue of Samsung's claim for infringement in this suit.

56. The Sharp Parties are entitled to judgment from this Court that the '177 patent is not infringed by the Sharp Parties, and is invalid and/or unenforceable.

THIRD DECLARATORY JUDGMENT COUNTERCLAIM

57. The Sharp Parties assert this counterclaim against Samsung.

58. The Sharp Parties incorporate by reference the allegations of paragraphs 1-44 hereof as though the same were set forth fully herein.

59. The Sharp Parties did not and do not directly infringe, indirectly infringe, contribute to or induce the infringement of any valid and enforceable claim of the '134 patent, and have not otherwise committed any acts in violation of 35 U.S.C. § 271.

60. The '134 patent is invalid and/or unenforceable for failing to meet the conditions of patentability set forth in 35 U.S.C. §§ 102, 103, 112, and/or 116.

61. An actual controversy exists between Samsung and the Sharp Parties concerning the alleged infringement, validity, and/or enforceability of the ‘134 patent by virtue of Samsung’s claim for infringement in this suit.

62. The Sharp Parties are entitled to judgment from this Court that the ‘134 patent is not infringed by the Sharp Parties, and is invalid and/or unenforceable.

FOURTH DECLARATORY JUDGMENT COUNTERCLAIM

63. The Sharp Parties assert this counterclaim against Samsung.

64. The Sharp Parties incorporate by reference the allegations of paragraphs 1-44 hereof as though the same were set forth fully herein.

65. The Sharp Parties did not and do not directly infringe, indirectly infringe, contribute to or induce the infringement of any valid and enforceable claim of the ‘310 patent, and have not otherwise committed any acts in violation of 35 U.S.C. § 271.

66. The ‘310 patent is invalid and/or unenforceable for failing to meet the conditions of patentability set forth in 35 U.S.C. §§ 102, 103, 112, and/or 116.

67. An actual controversy exists between Samsung and the Sharp Parties concerning the alleged infringement, validity, and/or enforceability of the ‘310 patent by virtue of Samsung’s claim for infringement in this suit.

68. The Sharp Parties are entitled to judgment from this Court that the ‘310 patent is not infringed by the Sharp Parties, and is invalid and/or unenforceable.

SHARP CORPORATION’S FIRST INFRINGEMENT CLAIM/COUNTERCLAIM

69. Sharp incorporates by reference paragraphs 1 through 44 and realleges them as though fully set forth herein.

70. On April 12, 2005, the United States Patent and Trademark Office issued U.S. Patent No. 6,879,364, entitled "Liquid Crystal Display Apparatus Having Alignment Control for Brightness and Response" ("the '364 patent"). A copy of the '364 patent is attached hereto as Exhibit A.

71. Sharp is the owner of all rights, title and interest in and to the '364 patent.

72. On information and belief, Samsung, SEA and SSI have been and are now infringing, contributorily infringing and/or actively inducing infringement of the '364 patent in violation of 35 U.S.C. § 271 by making, using, offering to sell, selling, causing to be sold, causing to be imported and/or importing in the United States of America LCD Modules and LCD Products that practice methods that fall within the scope of one or more claims of the '364 patent. Samsung, SEA and SSI's infringement is literal and/or under the doctrine of equivalents.

73. As a consequence of the infringement by Samsung, SEA and SSI, Sharp is entitled to recover damages adequate to compensate it for the infringement complained of herein, but in no event less than a reasonable royalty.

74. Samsung, SEA and SSI's infringement has irreparably injured and will continue to irreparably injure Sharp, unless and until such infringement is enjoined by this Court.

SHARP CORPORATION'S SECOND INFRINGEMENT CLAIM/COUNTERCLAIM

75. Sharp incorporates by reference paragraphs 1 through 44 and realleges them as though fully set forth herein.

76. On October 4, 2005, the United States Patent and Trademark Office issued U.S. Patent No. 6,952,192, entitled "Liquid Crystal Display Device and Its Drive Method" ("the '192 patent"). A copy of the '192 patent is attached hereto as Exhibit B.

77. Sharp is the owner of all right, title and interest in and to the '192 patent.

78. On information and belief, Samsung, SEA and SSI have been and are now infringing, contributorily infringing and/or actively inducing infringement of the ‘192 patent in violation of 35 U.S.C. § 271 by making, using, offering to sell, selling, causing to be sold, causing to be imported and/or importing in the United States of America LCD Modules and LCD Products falling within the scope of one or more claims of the ‘192 patent. Samsung, SEA and SSI’s infringement is literal and/or under the doctrine of equivalents.

79. On information and belief, Samsung, SEA and SSI’s infringement of the ‘192 patent is willful.

80. As a consequence of Samsung, SEA and SSI’s infringement, Sharp is entitled to recover damages adequate to compensate it for the infringement complained of herein, but in no event less than a reasonable royalty.

81. Samsung, SEA and SSI’s infringement has irreparably injured and will continue to irreparably injure Sharp, unless and until such infringement is enjoined by this Court.

SHARP CORPORATION’S THIRD INFRINGEMENT CLAIM/COUNTERCLAIM

82. Sharp incorporates by reference paragraphs 1 through 44 and realleges them as though fully set forth herein.

83. On December 4, 2007, the United States Patent and Trademark Office issued U.S. Patent No. 7,304,626, entitled “Display Device and Display Method” (“the ‘626 patent”). A copy of the ‘626 patent is attached hereto as Exhibit C.

84. Sharp is the owner of all right, title and interest in and to the ‘626 patent.

85. On information and belief, Samsung, SEA and SSI have been and are now infringing, contributorily infringing and/or actively inducing infringement of the ‘626 patent in violation of 35 U.S.C. § 271 by making, using, offering to sell, selling, causing to be sold,

causing to be imported and/or importing in the United States of America LCD Modules and LCD Products falling within the scope of one or more claims of the '626 patent. Samsung, SEA and SSI's infringement is literal and/or under the doctrine of equivalents.

86. As a consequence of Samsung, SEA and SSI's infringement, Sharp is entitled to recover damages adequate to compensate it for the infringement complained of herein, but in no event less than a reasonable royalty.

87. Samsung, SEA and SSI's infringement has irreparably injured and will continue to irreparably injure Sharp, unless and until such infringement is enjoined by this Court.

SHARP CORPORATION'S FOURTH INFRINGEMENT CLAIM/COUNTERCLAIM

88. Sharp incorporates by reference paragraphs 1 through 44 and realleges them as though fully set forth herein.

89. On December 4, 2007, the United States Patent and Trademark Office issued U.S. Patent No. 7,304,703, entitled "Vertically Aligned (VA) Liquid Crystal Display Device" ("the '703 patent"). A copy of the '703 patent is attached hereto as Exhibit D.

90. Sharp is the owner of all right, title and interest in and to the '703 patent.

91. On information and belief, Samsung, SEA and SSI have been and are now infringing, contributorily infringing and/or actively inducing infringement of the '703 patent in violation of 35 U.S.C. § 271 by making, using, offering to sell, selling, causing to be sold, causing to be imported and/or importing in the United States of America LCD Modules and LCD Products falling within the scope of one or more claims of the '703 patent. Samsung, SEA and SSI's infringement is literal and/or under the doctrine of equivalents.

92. As a consequence of Samsung, SEA and SSI's infringement, Sharp is entitled to recover damages adequate to compensate it for the infringement complained of herein, but in no event less than a reasonable royalty.

93. Samsung, SEA and SSI's infringement has irreparably injured and will continue to irreparably injure Sharp, unless and until such infringement is enjoined by this Court.

PRAYER FOR RELIEF

WHEREFORE, Sharp, SEC and/or SEMA request that the Court:

A. Dismiss each of Samsung's claims with prejudice;

B. Declare that Sharp, SEC and SEMA do not infringe, actively induce infringement or contribute to the infringement of any claim of the '196, '666, '311, or '344 patents;

C. Declare that each and every claim of the '196, '666, '311, and '344 patents is invalid;

D. Declare that the '196, '666, '311, and '344 patents are unenforceable;

E. Declare that Samsung is not entitled to any of the injunctive relief requested by Samsung;

F. Adjudge that the '364, '192, '626, and '703 patents are valid and enforceable;

G. Adjudge that Samsung is infringing and/or has infringed, and has contributed to and induced infringement of, the '364, '192, '626, and '703 patents, and that such infringement is willful and deliberate;

H. Adjudge that SEA is infringing and/or has infringed, and has contributed to and induced infringement of, the '364, '192, '626, and '703 patents, and that such infringement is willful and deliberate;

I. Adjudge that SSI is infringing and/or has infringed, and have contributed to and induced infringement of, the '364, '192, '626, and '703 patents, and that such infringement is willful and deliberate;

J. Enjoin Samsung and its affiliates, subsidiaries, officers, directors, employees, agents, representatives, licensees, successors, assigns and all those acting for it and on its behalf, or acting in concert with it, from further infringement of the '364, '192, '626, and '703 patents;

K. Enjoin SEA and its affiliates, subsidiaries, officers, directors, employees, agents, representatives, licensees, successors, assigns and all those acting for it and on its behalf, or acting in concert with it, from further infringement of the '364, '192, '626, and '703 patents;

L. Enjoin SSI and its affiliates, subsidiaries, officers, directors, employees, agents, representatives, licensees, successors, assigns and all those acting for it and on their its behalf, or acting in concert with it, from further infringement of the '364, '192, '626, and '703 patents;

M. Award compensatory damages to Sharp, including but not limited to lost profits, but in no event less than a reasonable royalty, together with interest;

N. Declare this to be an exceptional case and award treble damages to Sharp for defendants' willful infringement of the '192 patent;

O. Award Sharp, SEC and SEMA their costs and attorneys' fees pursuant to 35 U.S.C. § 285;

P. Award Sharp, SEC and SEMA such other and further relief as the Court deems just and proper.

DEMAND FOR JURY TRIAL

Sharp, SEC and SEMA hereby demand a jury trial on all issues so triable.

MORRIS, NICHOLS, ARSHT & TUNNELL LLP

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January 30, 2008

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CERTIFICATE OF SERVICE

I, Rodger D. Smith II, hereby certify that on January 30, 2008, I caused the foregoing to be electronically filed with the Clerk of the Court using CM/ECF, which will send notification of such filing to:

William J. Marsden, Jr., Esquire
FISH & RICHARDSON PC

I also certify that copies were caused to be served on January 30, 2008, upon the following in the manner indicated:

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EXHIBIT A

US006879364B1

(12) **United States Patent**
Sasaki et al.

(10) **Patent No.: US 6,879,364 B1**
(45) **Date of Patent: Apr. 12, 2005**

(54) **LIQUID CRYSTAL DISPLAY APPARATUS HAVING ALIGNMENT CONTROL FOR BRIGHTNESS AND RESPONSE**

(75) Inventors: **Takahiro Sasaki**, Kawasaki (JP); **Arihiro Takeda**, Kawasaki (JP); **Katsufumi Ohmuro**, Kawasaki (JP); **Hideo Chida**, Kawasaki (JP); **Yoshio Koike**, Kawasaki (JP); **Kimiaki Nakamura**, Kawasaki (JP); **Kunihiro Tashiro**, Kawasaki (JP)

(73) Assignee: **Fujitsu Display Technologies Corporation**, Kawasaki (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **10/621,789**

(22) Filed: **Jul. 17, 2003**

Related U.S. Application Data

(62) Division of application No. 09/398,126, filed on Sep. 16, 1999.

(30) **Foreign Application Priority Data**

Sep. 18, 1998 (JP) 10-264849
Aug. 13, 1999 (JP) 11-229249

(51) **Int. Cl.**[7] **G02F 1/13**
(52) **U.S. Cl.** **349/129**; 349/130
(58) **Field of Search** 349/129, 130

(56) **References Cited**

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6,067,141 A 5/2000 Yamada et al. 349/129
6,188,457 B1 2/2001 Liu 349/124
6,313,899 B1 11/2001 Wu et al. 349/130
6,567,144 B1 * 5/2003 Kim et al. 349/128

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EP 0 854 377 7/1998
JP 7199193 8/1995

OTHER PUBLICATIONS

"A Super–High–Image–Quality Multi–Domain Vertical Alignment LCD by New Rubbing–Less Technology"; Takeda et al.; SID Digest, 1998; pp. 1077–1080.

* cited by examiner

Primary Examiner—James A. Dudek
(74) *Attorney, Agent, or Firm*—Greer, Burns & Crain, Ltd.

(57) **ABSTRACT**

A liquid crystal display apparatus including a pair of substrates having electrodes and vertical alignment layers. A liquid crystal having a negative anisotropy of dielectric is inserted between the substrates. Each substrate has linearly arranged alignment control structures for controlling the alignment of the liquid crystal. The alignment control structures are formed in the form of projections or slits. Each alignment control structure is formed of a plurality of constituent units. In addition, means for forming a boundary of alignment of liquid crystal (singular point in director field) to control the liquid crystal located on the alignment control structures.

9 Claims, 103 Drawing Sheets

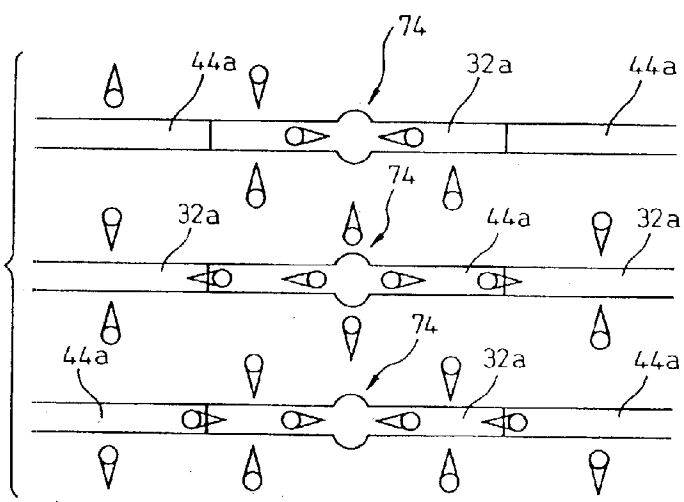

Fig. 1

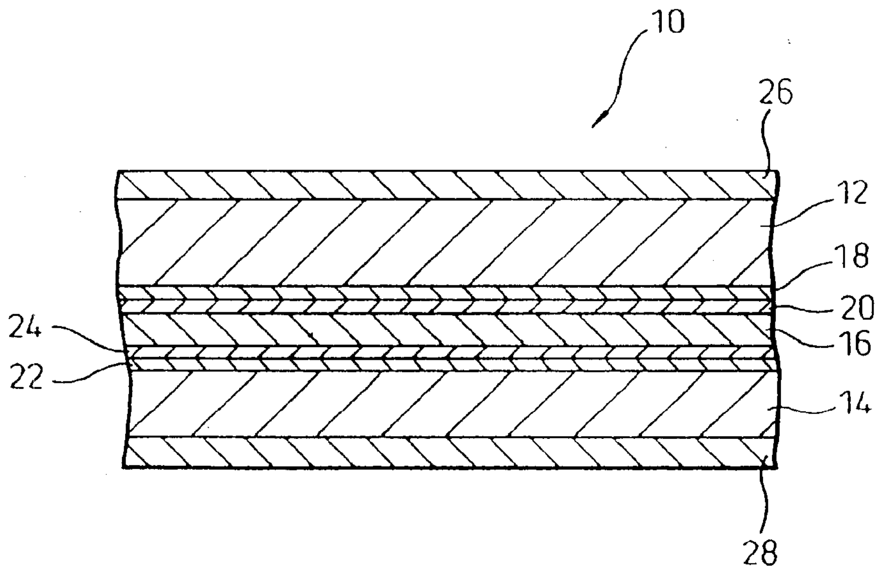
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Fig. 2

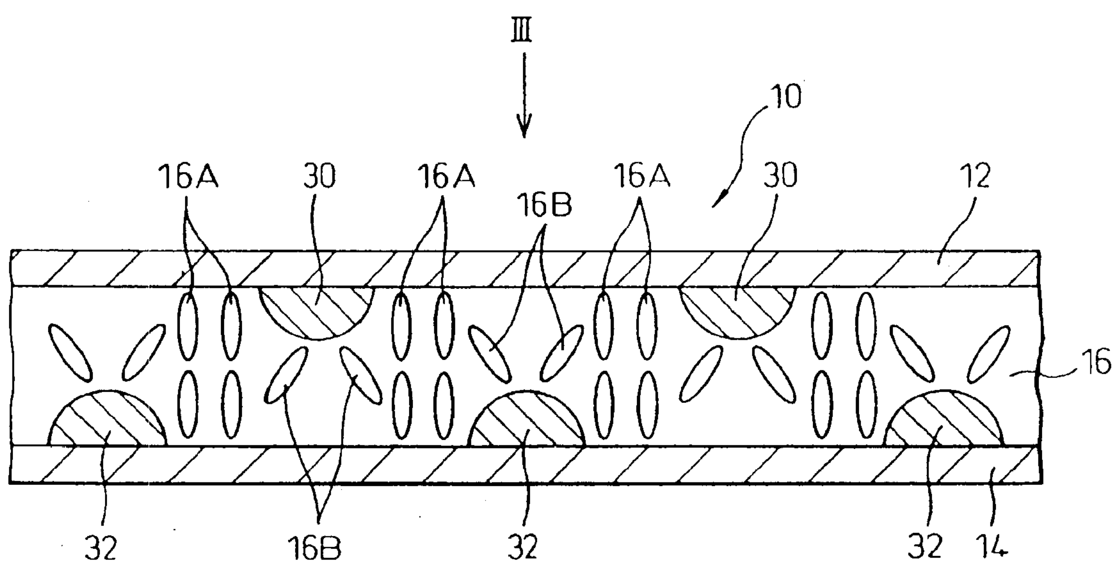
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Fig. 3

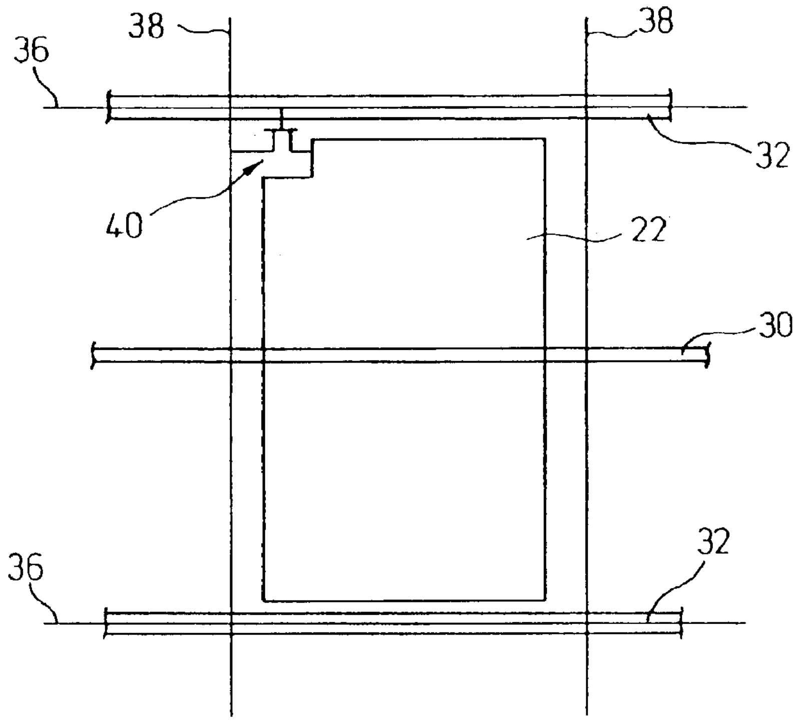


Fig. 4A

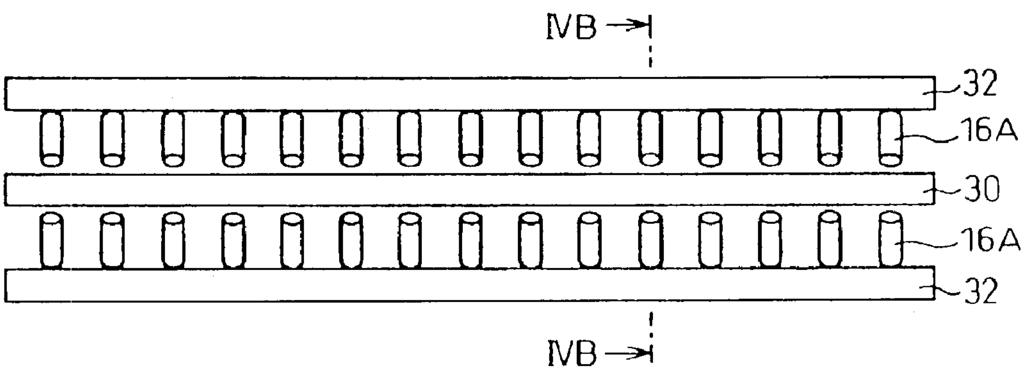


Fig. 4B

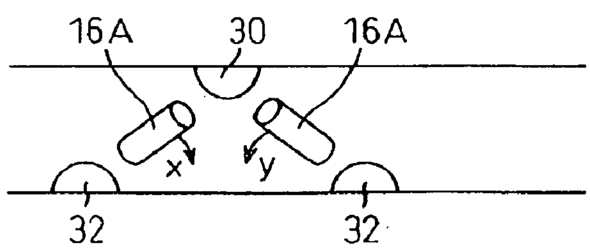


Fig. 5

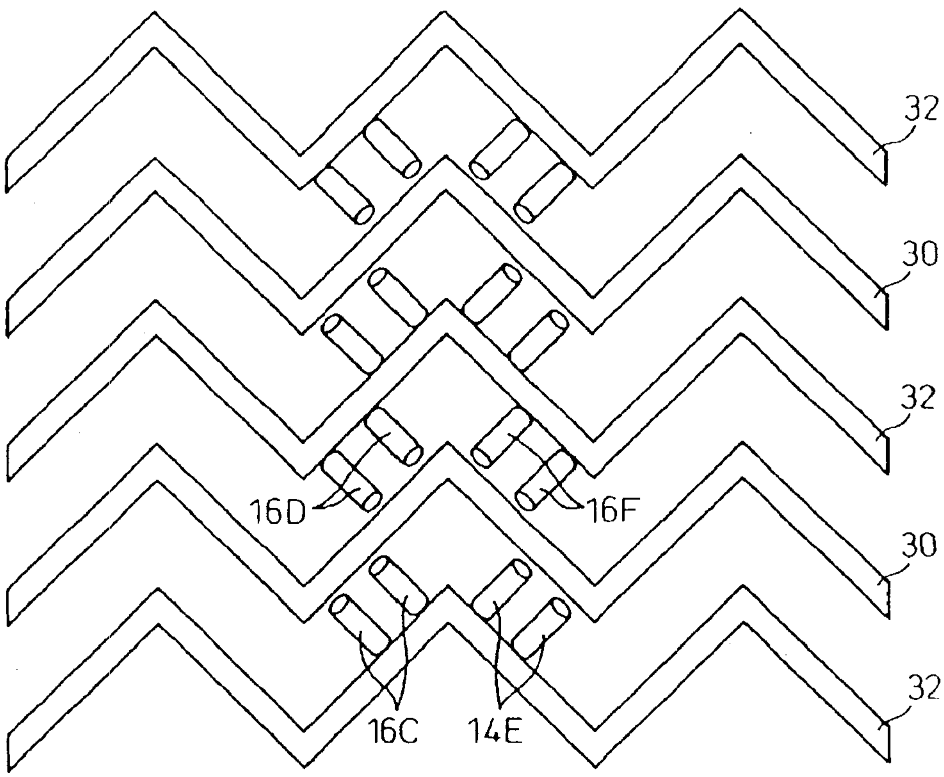


Fig. 6

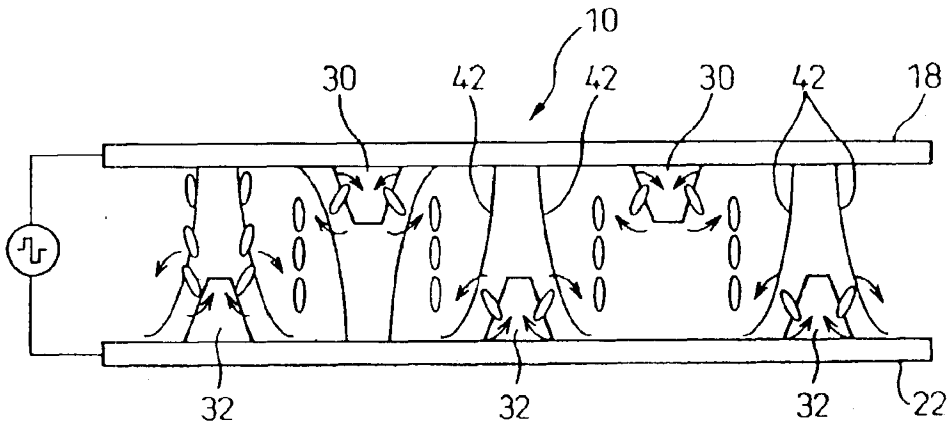


Fig. 7

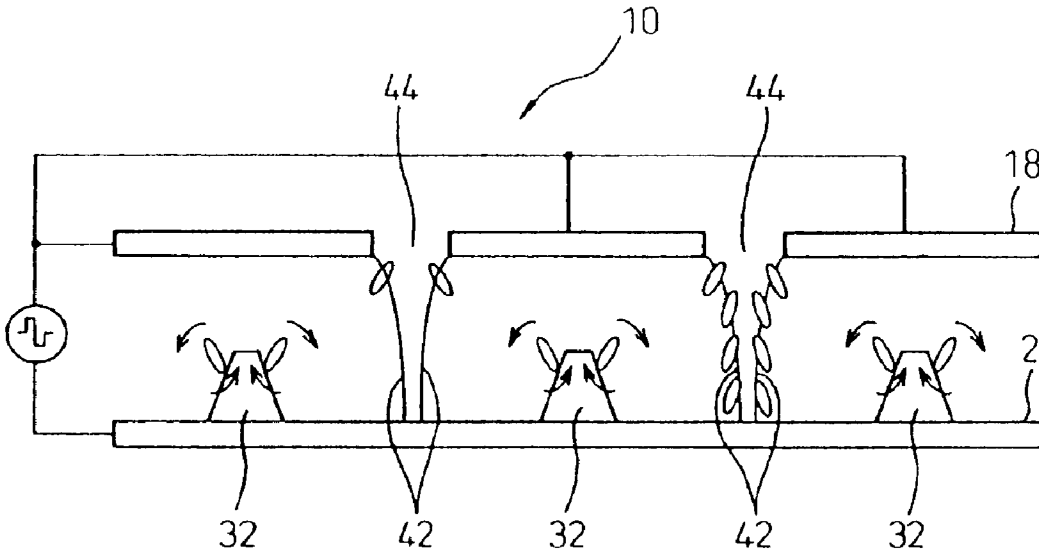


Fig. 8

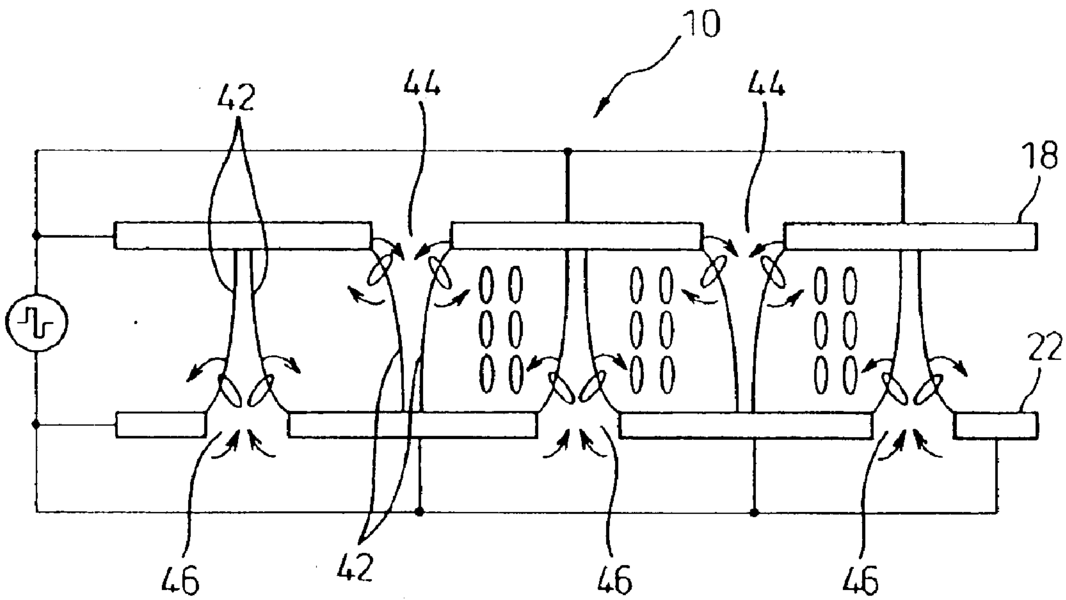


Fig. 9

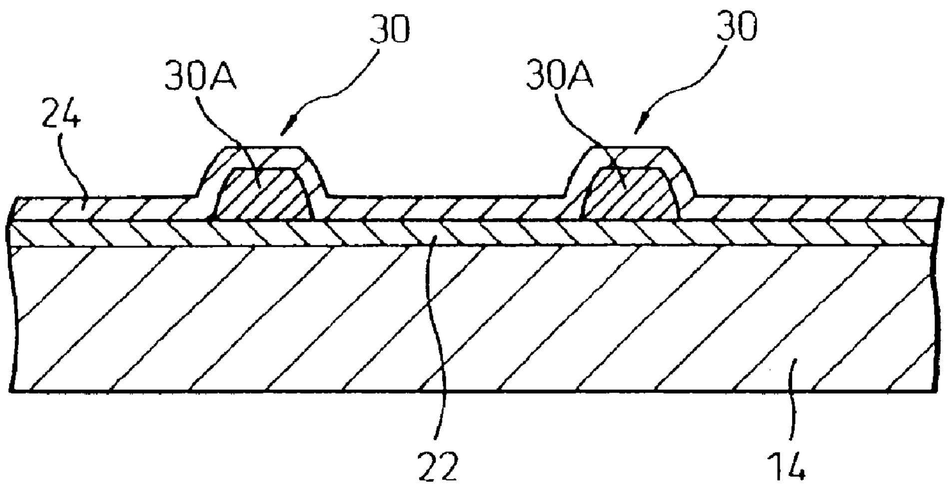


Fig. 10

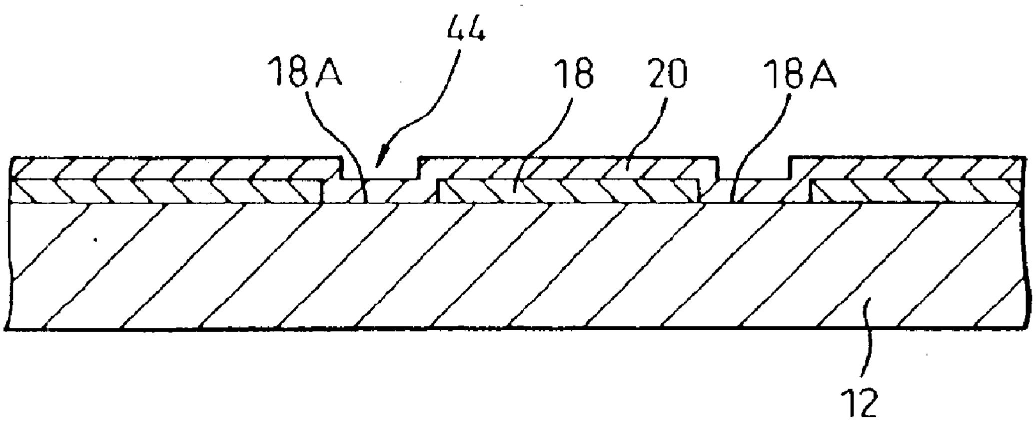


Fig. 11

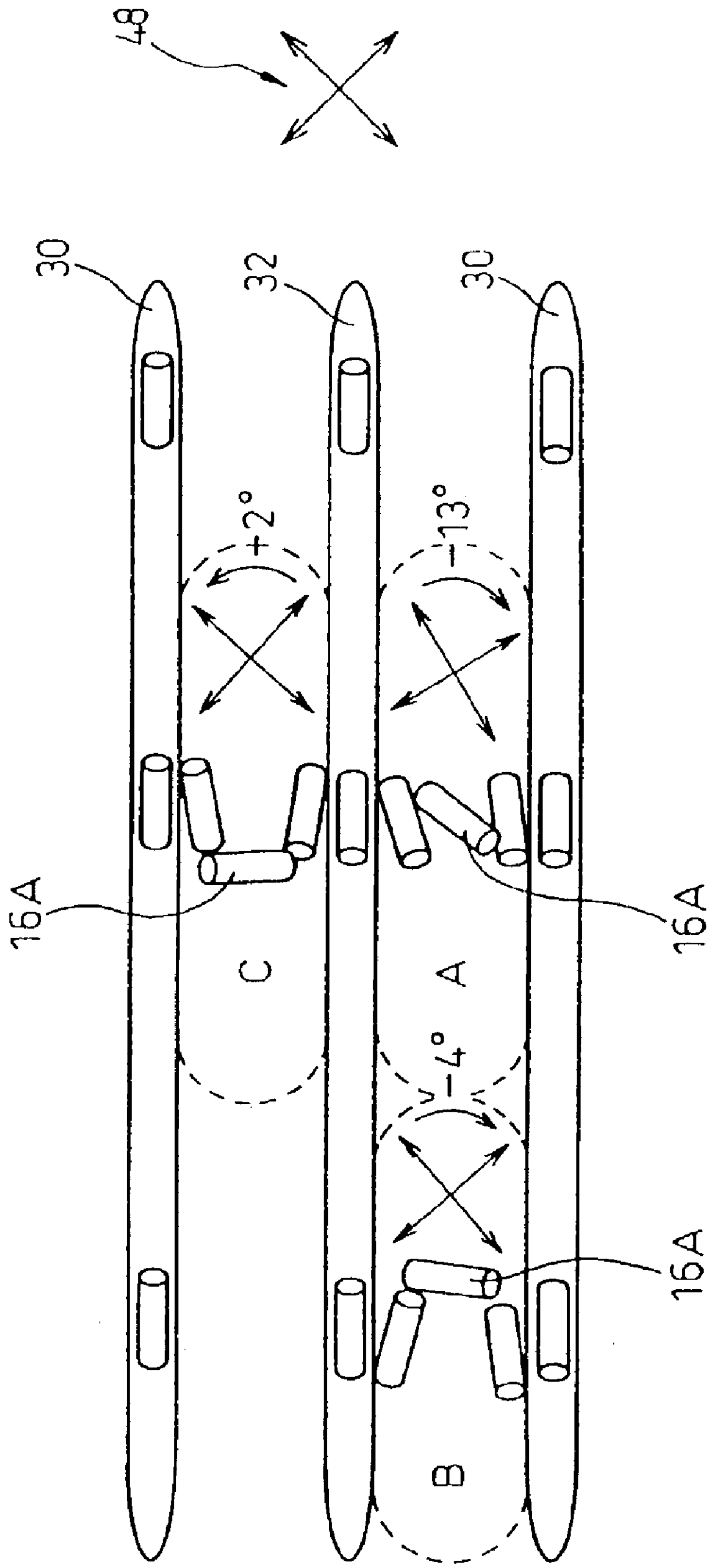
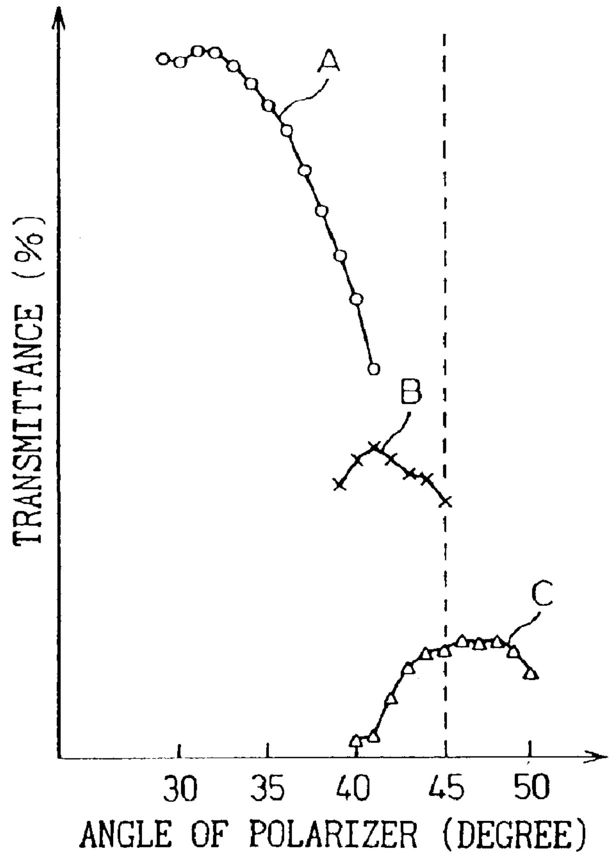
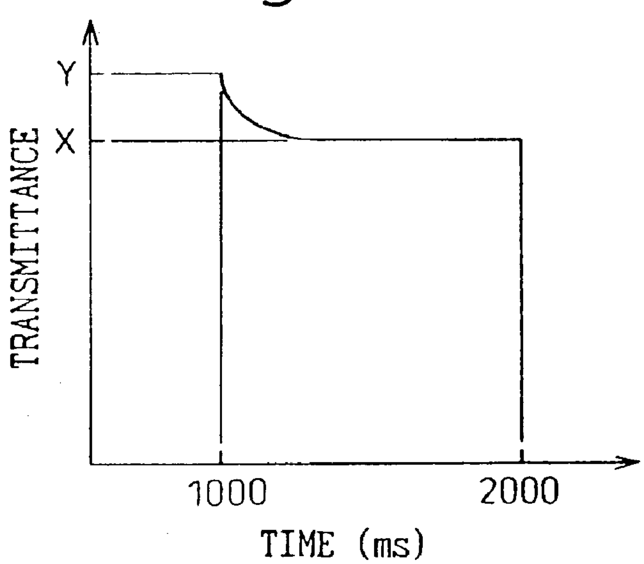


Fig. 12



TRANSMITTANCE (%)
A
B
C
30
35
40
45
50
ANGLE OF POLARIZER (DEGREE)

Fig. 13



TRANSMITTANCE
Y
X
1000
2000
TIME (ms)

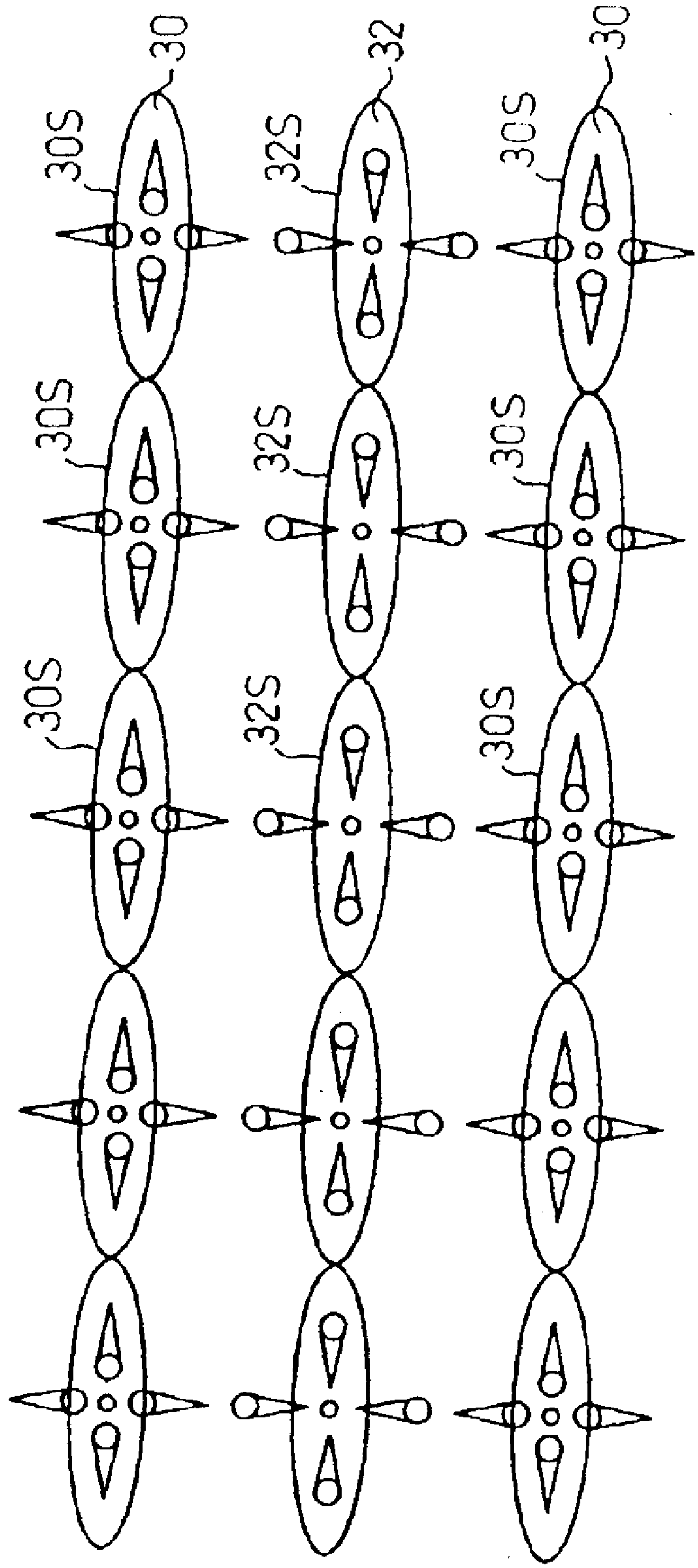


Fig.14

Fig.15

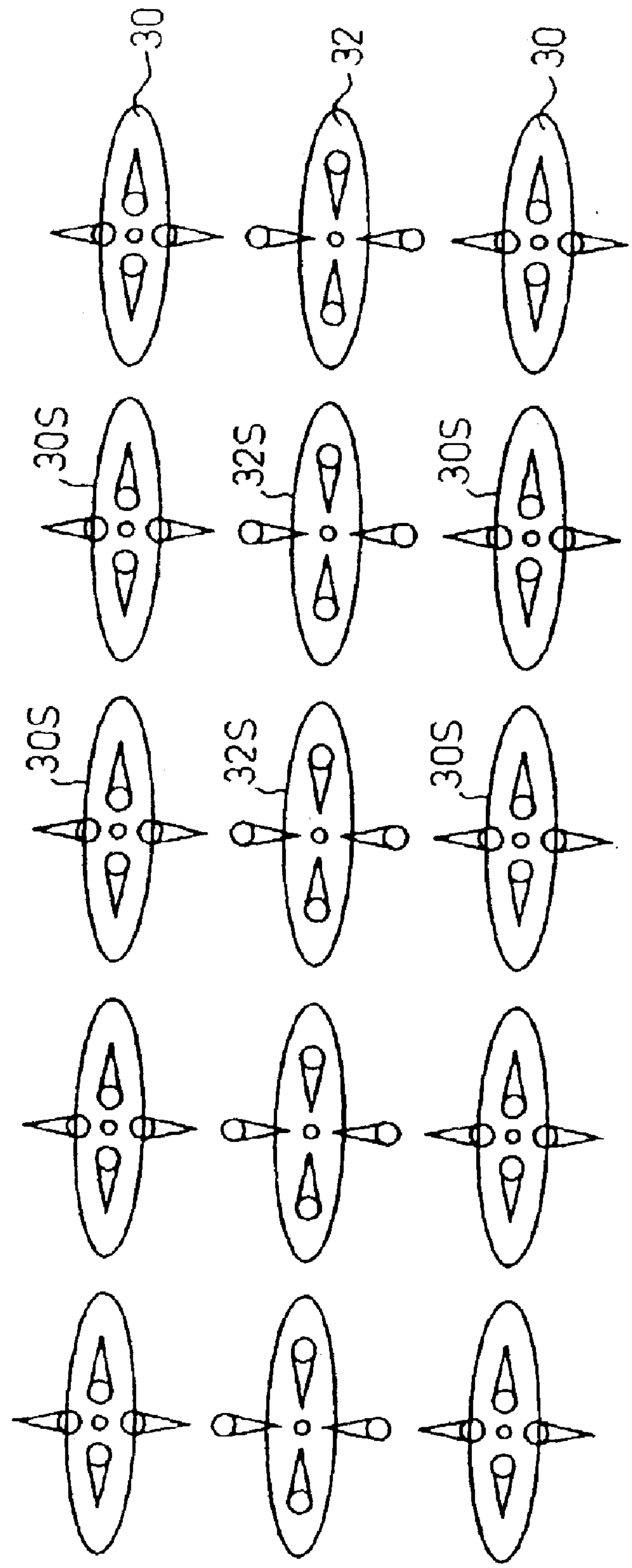


Fig.16

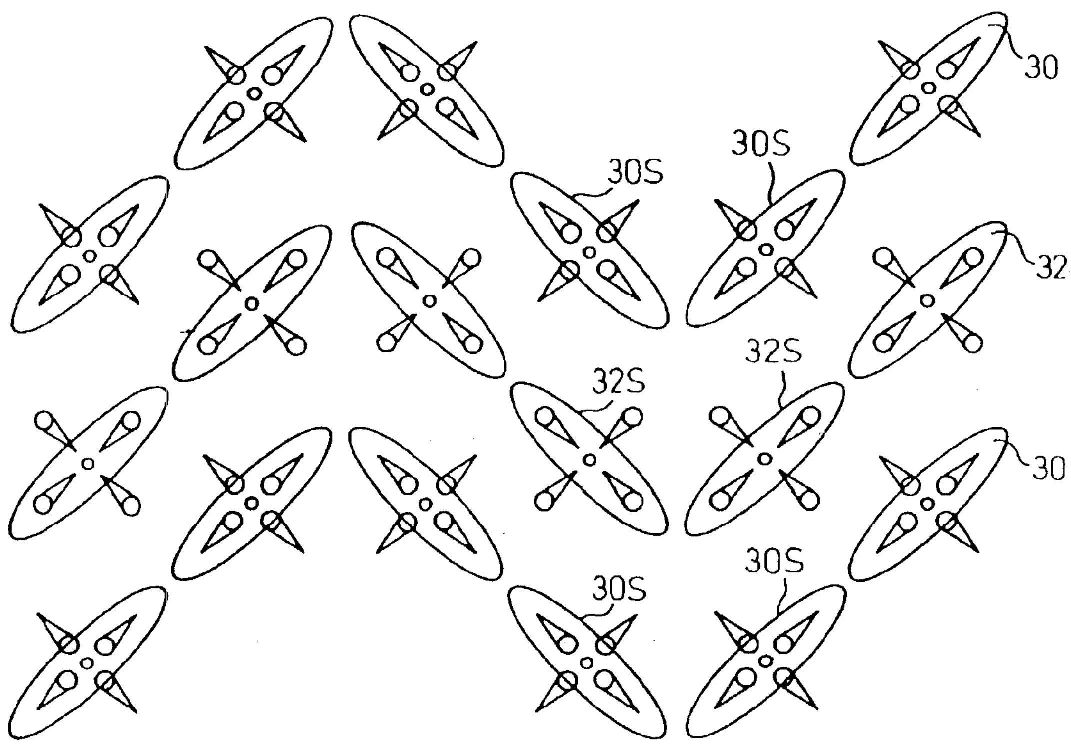


Fig.17

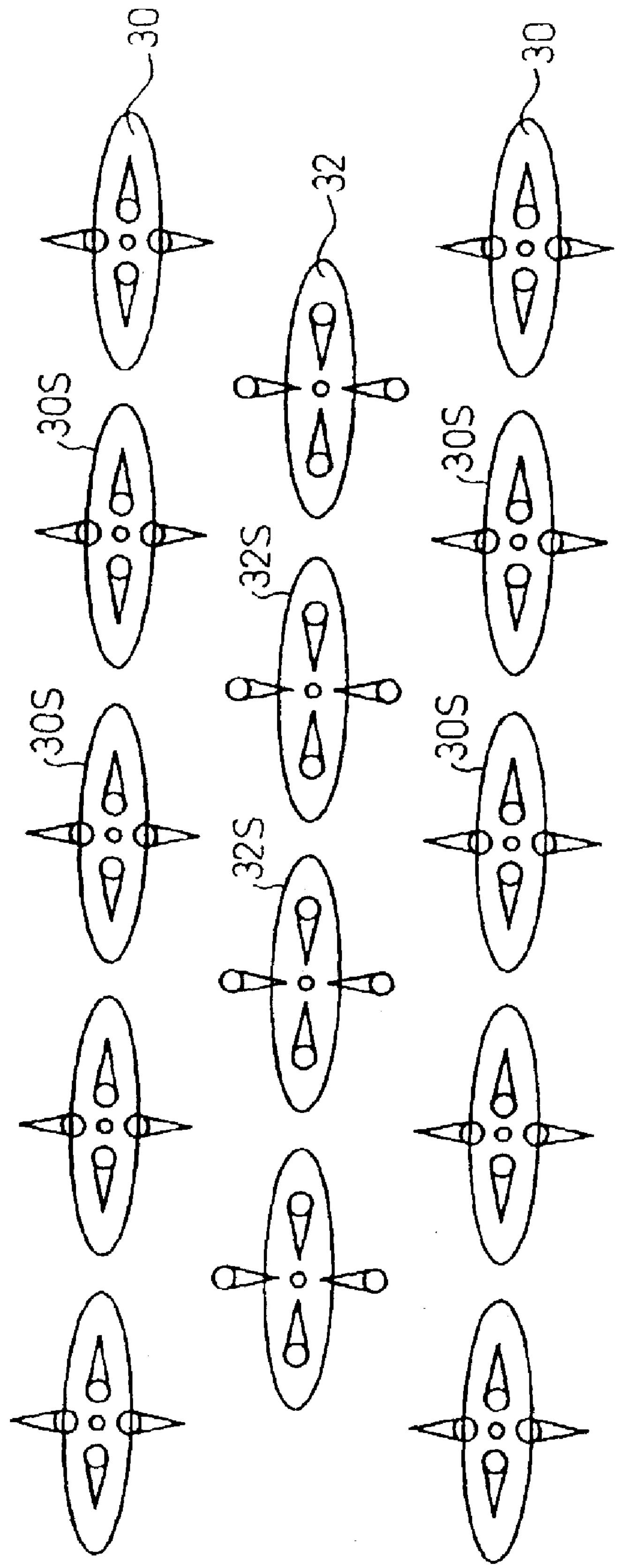


Fig.18

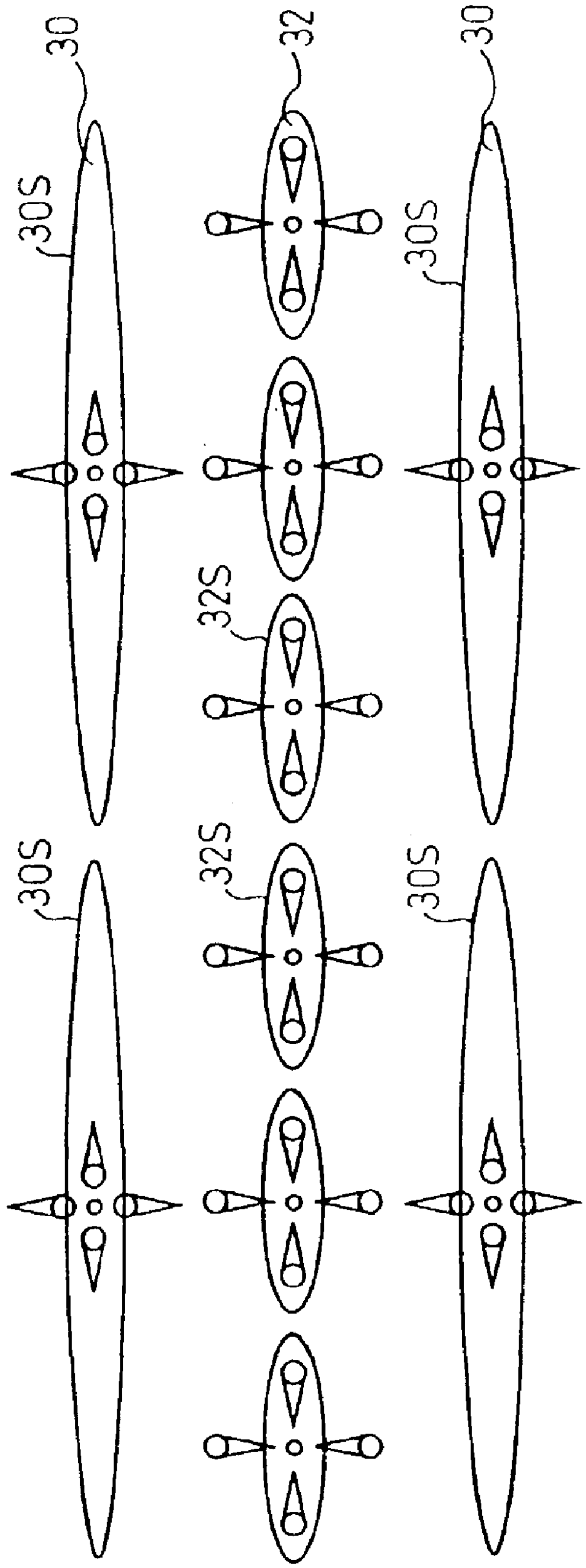


Fig.19

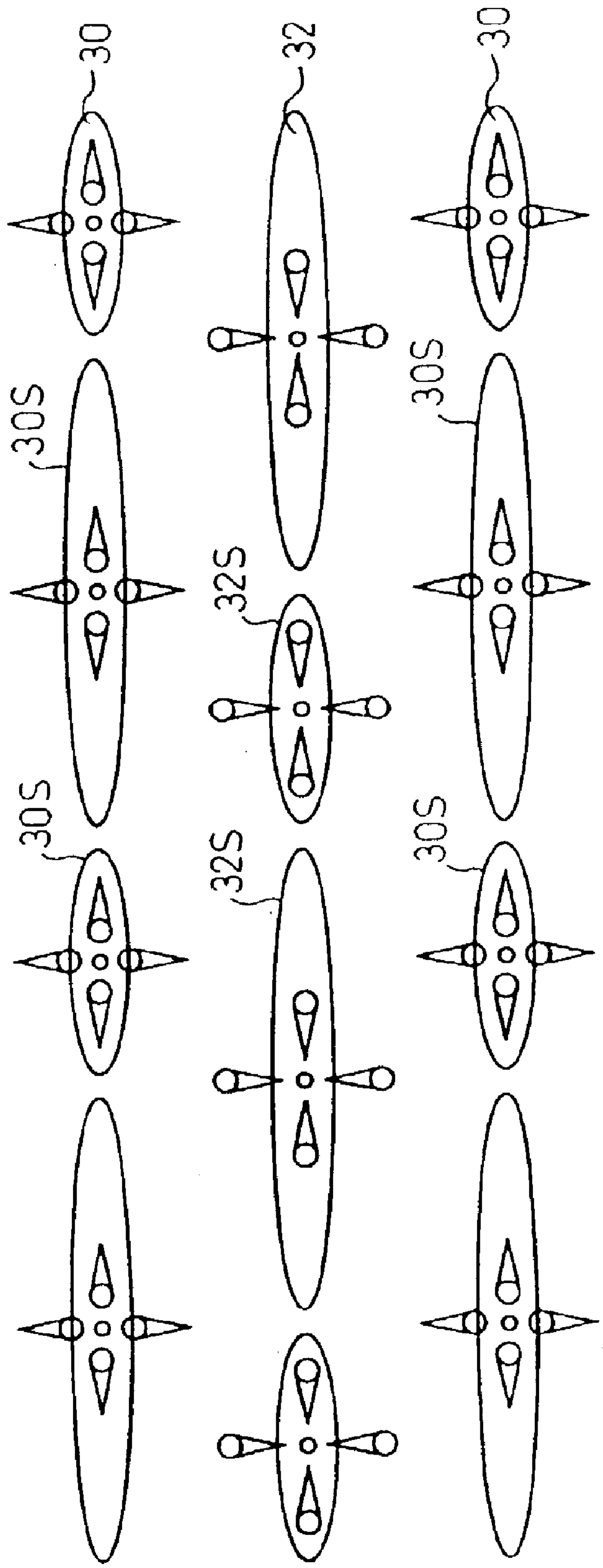


Fig.20

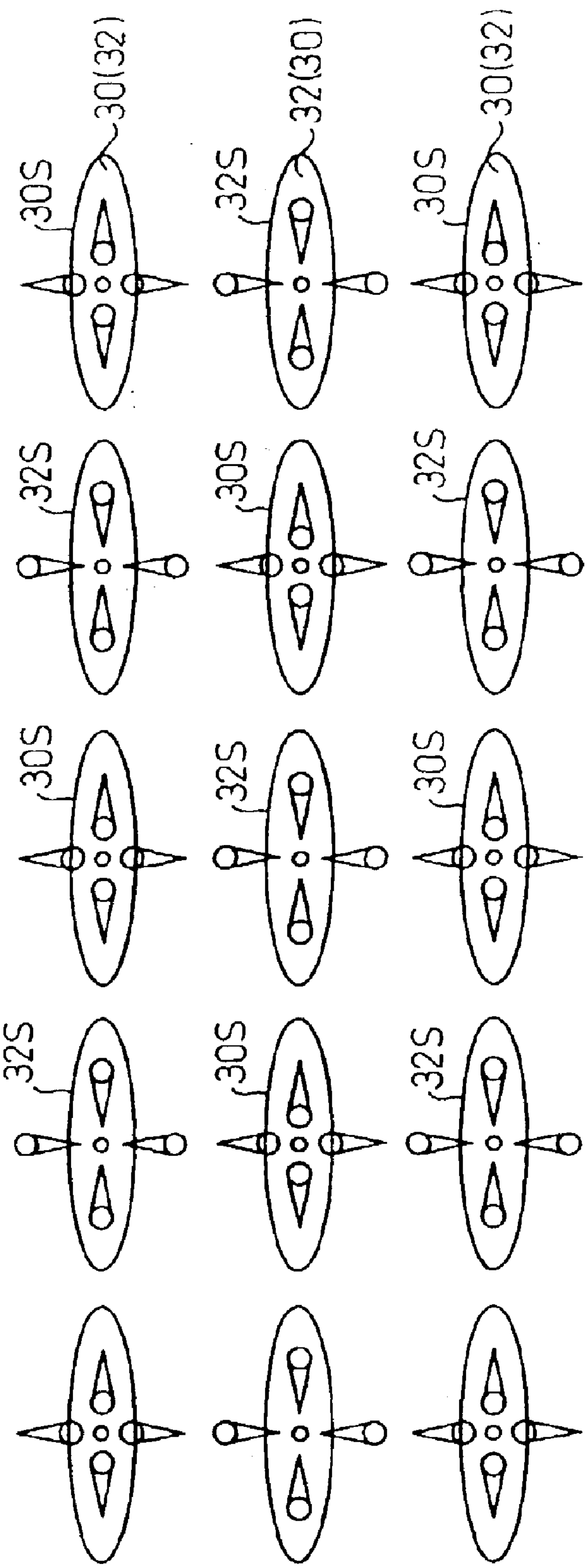


Fig. 21

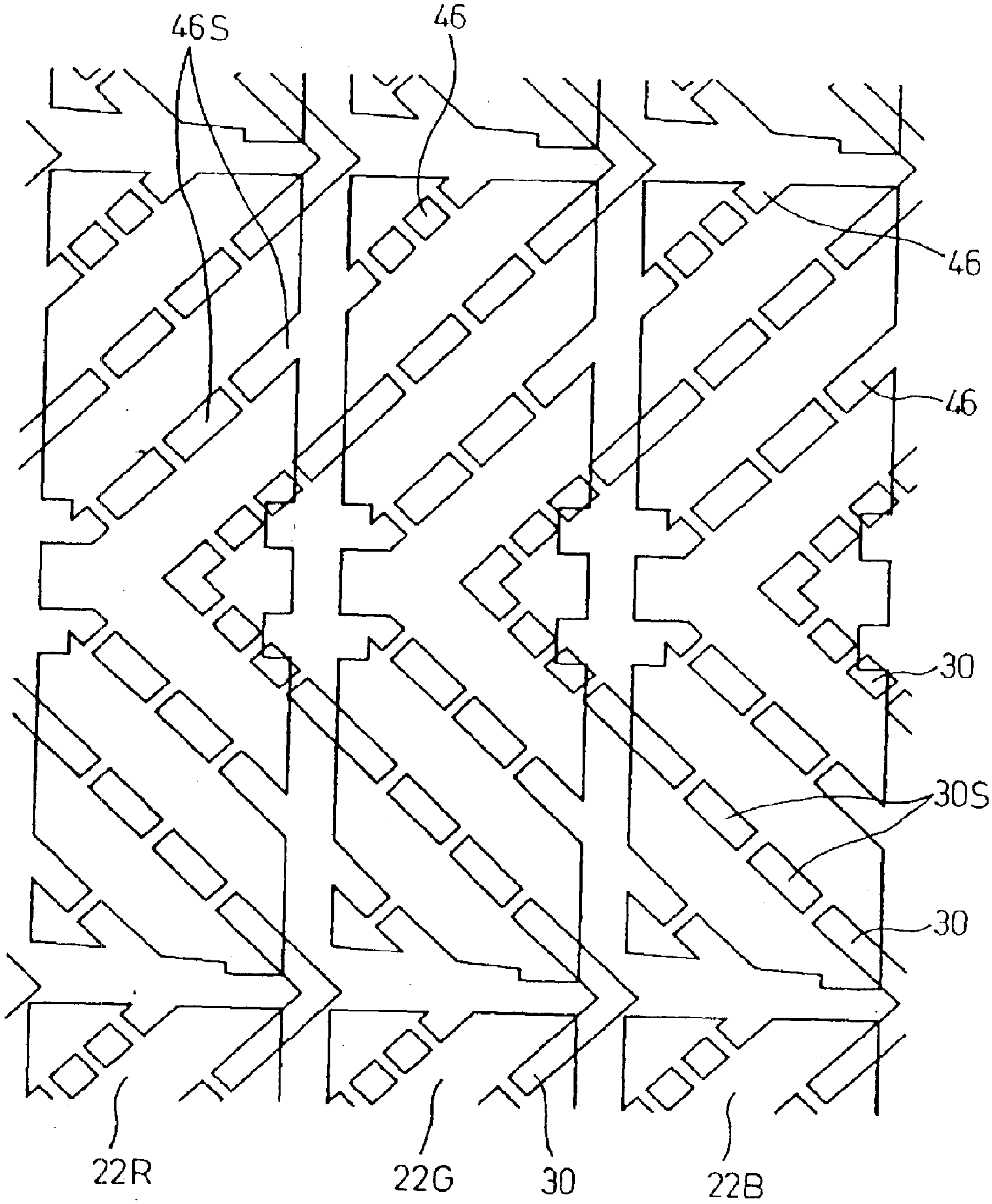


Fig. 22

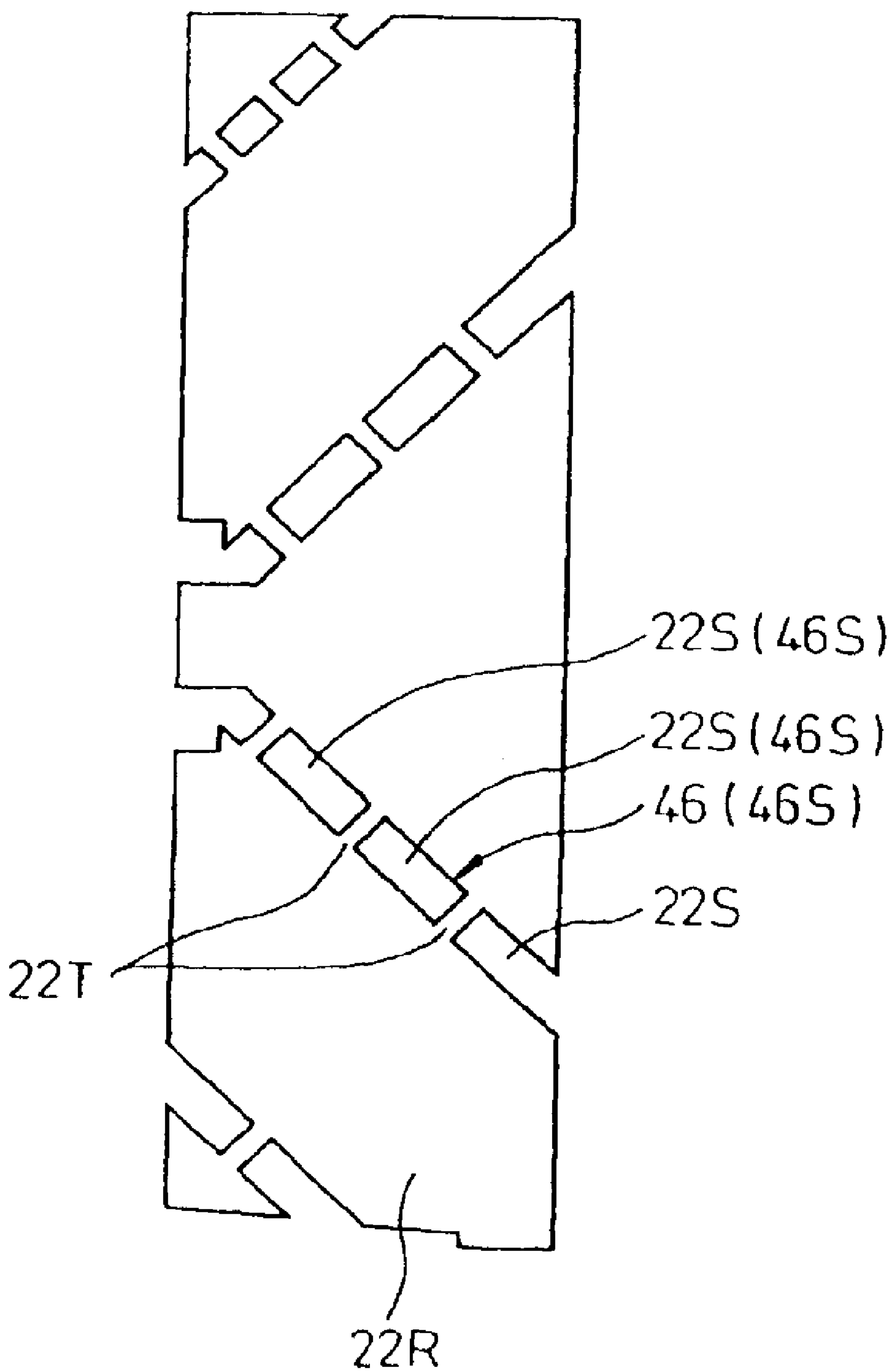


Fig. 23A

Fig. 23B

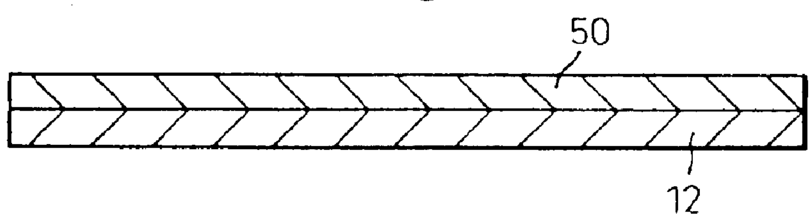


Fig. 23C

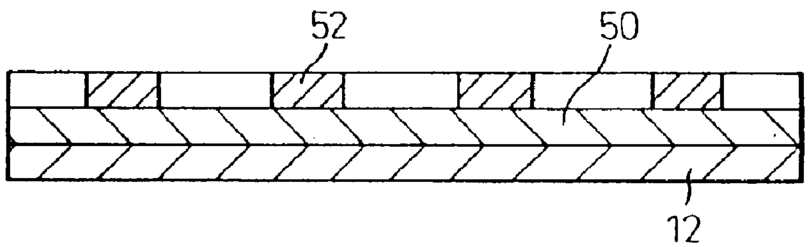


Fig. 23D

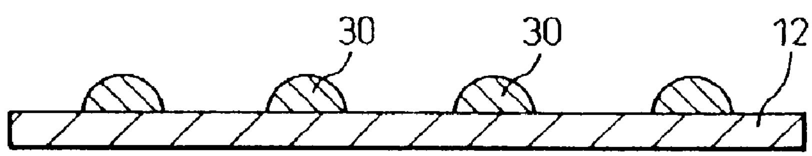


Fig. 23E

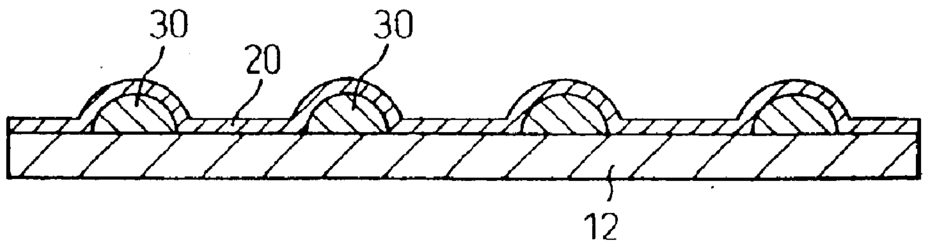


Fig. 24

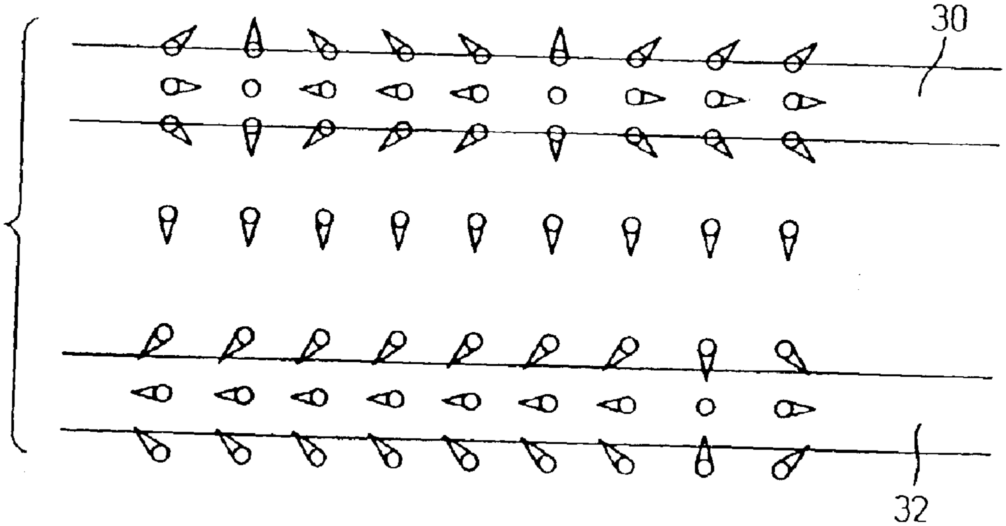


Fig. 25

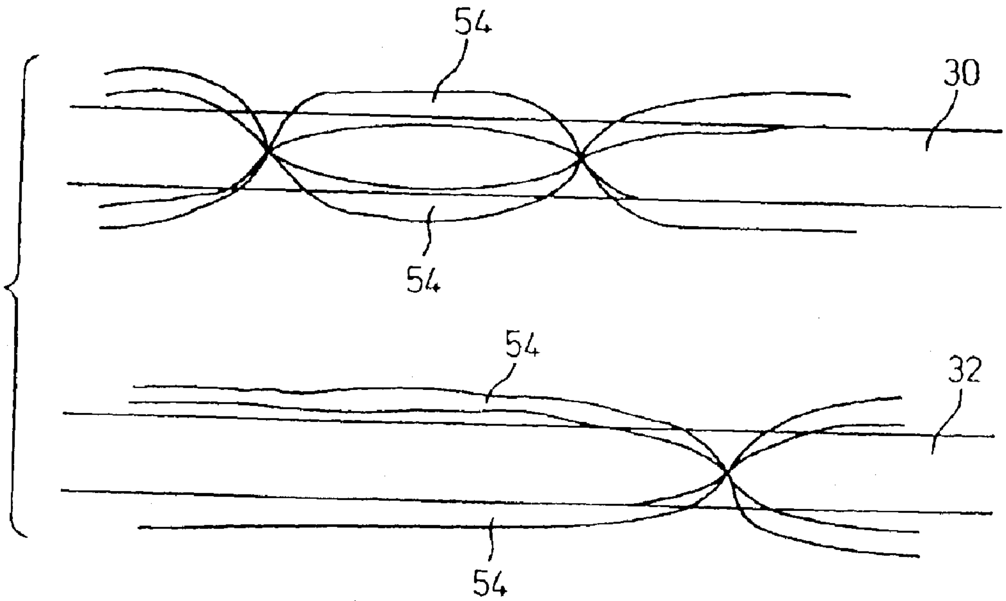


Fig. 26

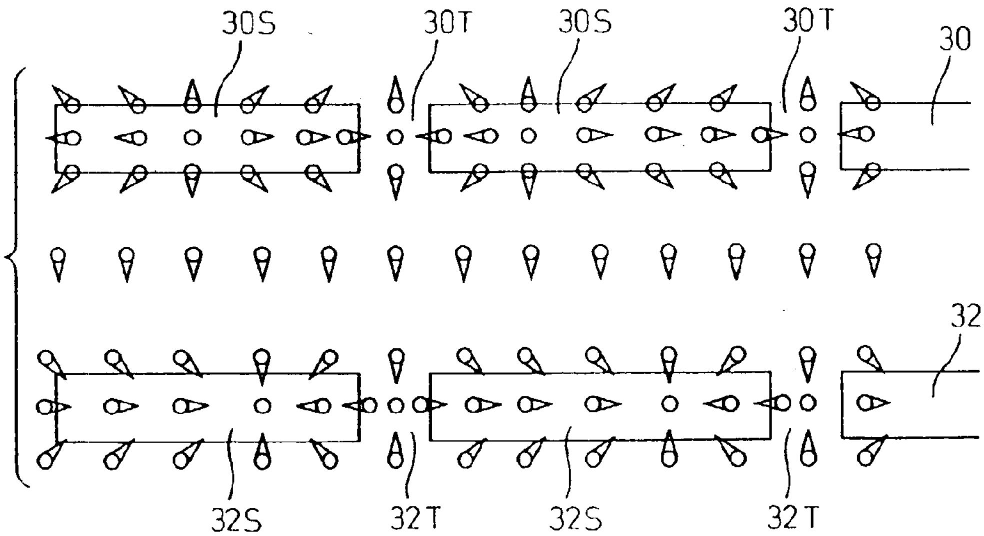

30S
30T
30S
30T
30
32
32S
32T
32S
32T

Fig. 27

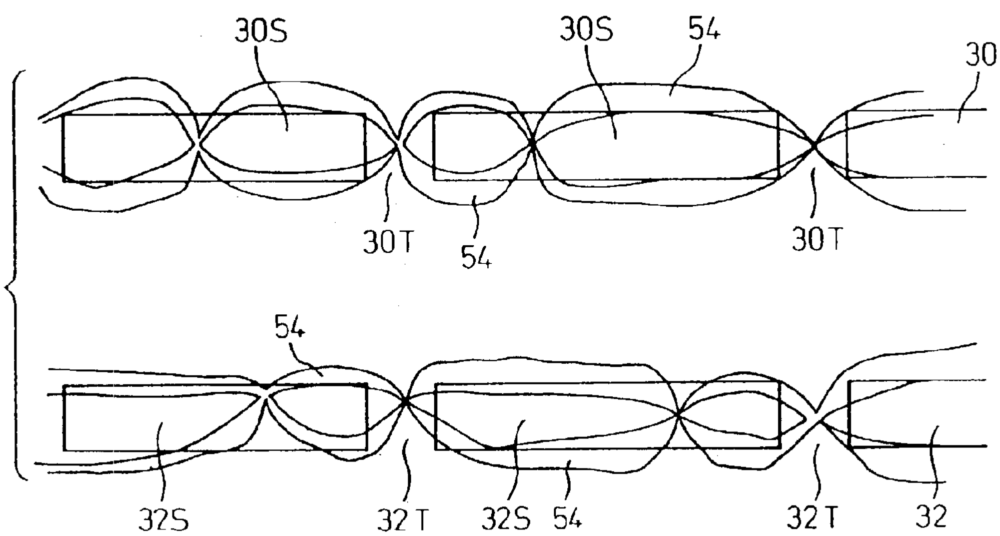

30S
30S
54
30
30T
54
30T
54
32S
32T
32S
54
32T
32

Fig. 28

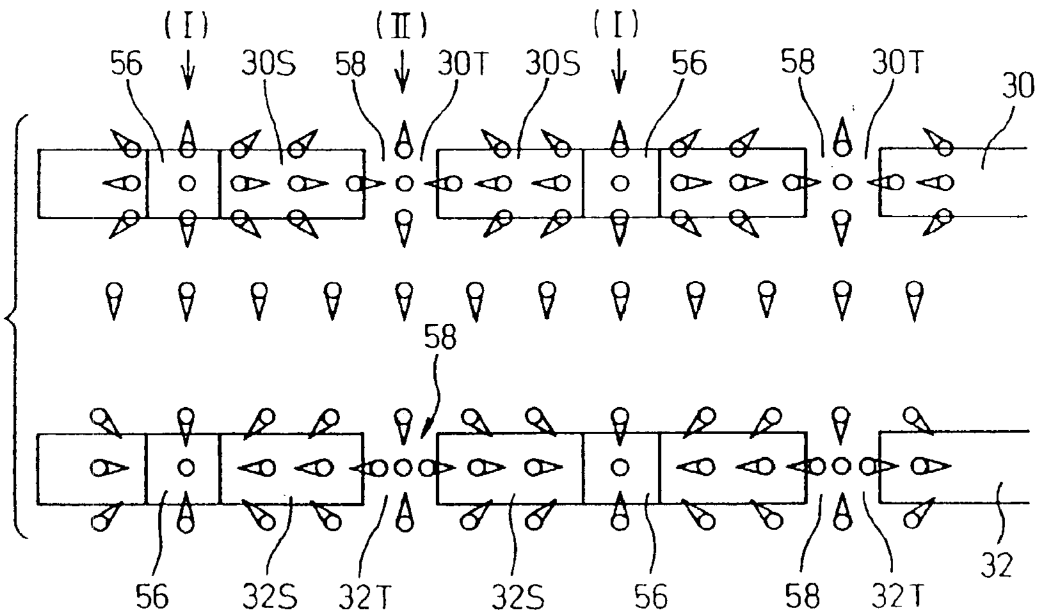

(I)
(II)
(I)
56
30S
58
30T
30S
56
58
30T
30
58
56
32S
32T
32S
56
58
32T
32

Fig. 29

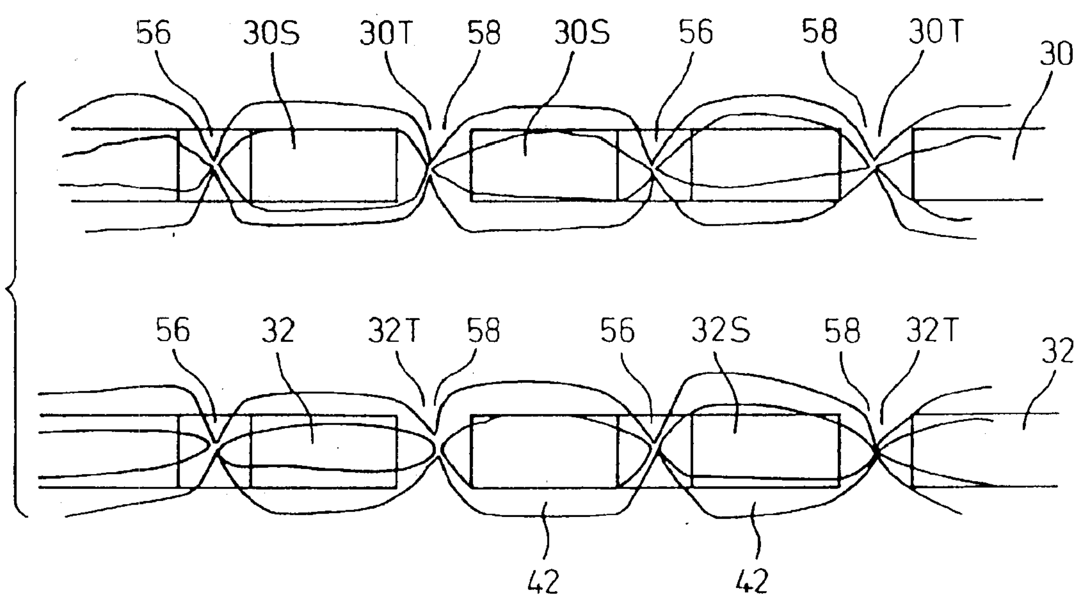

56
30S
30T
58
30S
56
58
30T
30
56
32
32T
58
56
32S
58
32T
32
42
42

Fig. 30

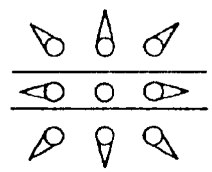
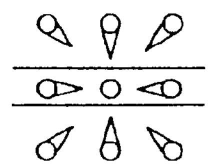
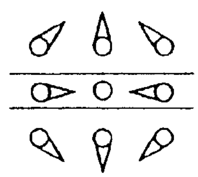
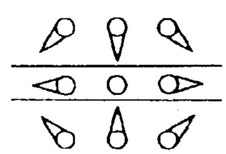
TYPE	FEATURE	
	ALIGNMENT ON UPPER PROJECTION	ALIGNMENT ON LOWER PROJECTION
(I)		
(II)		

Fig. 31

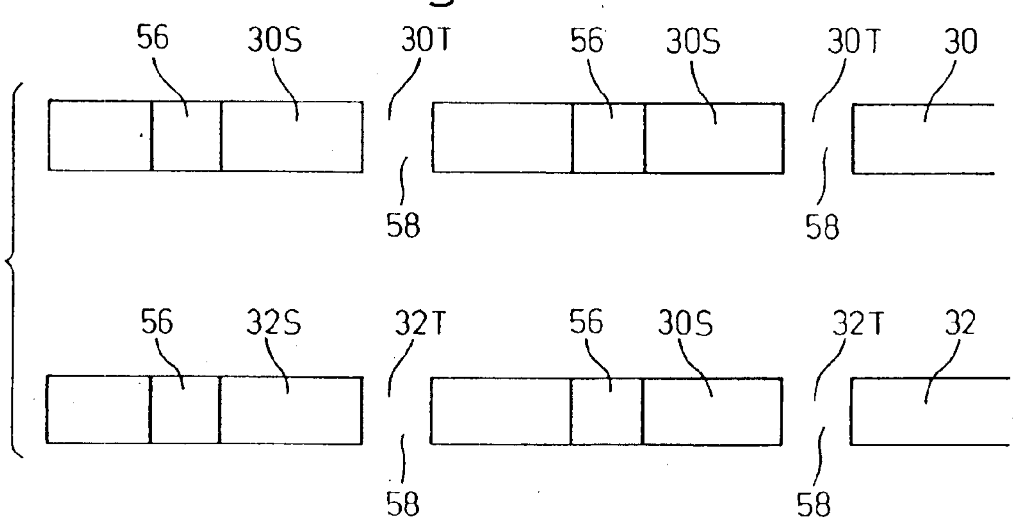


Fig. 32

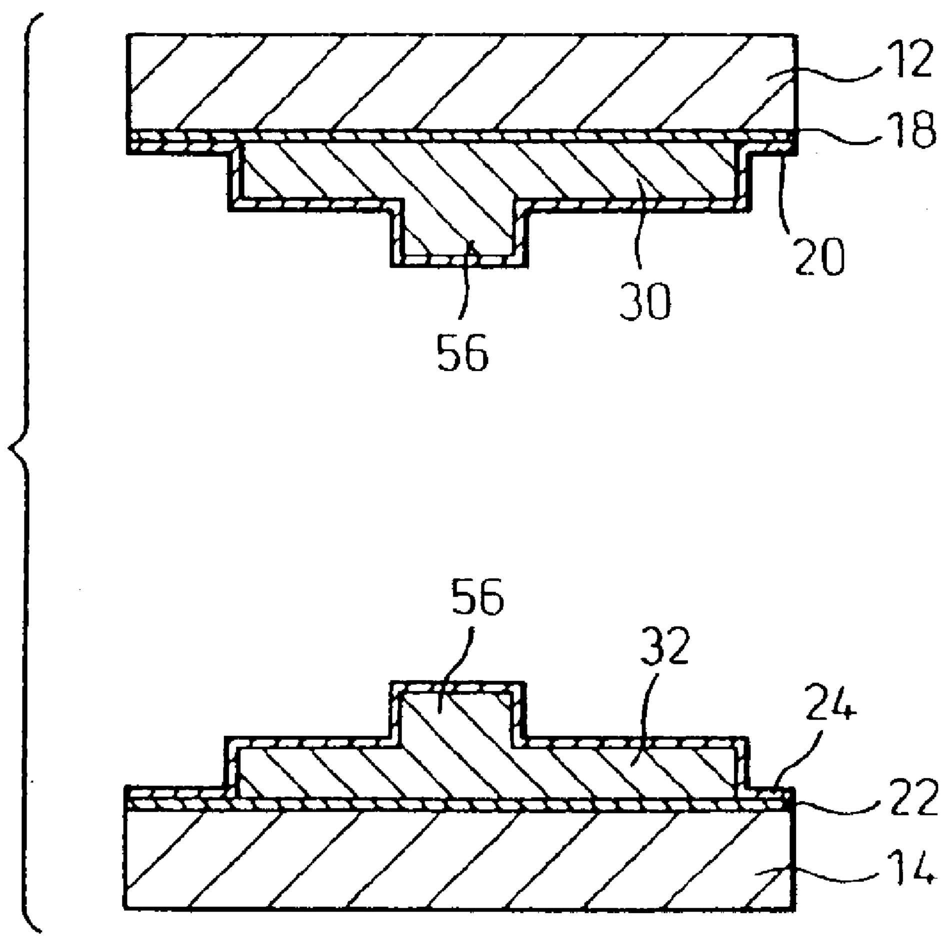


Fig. 33

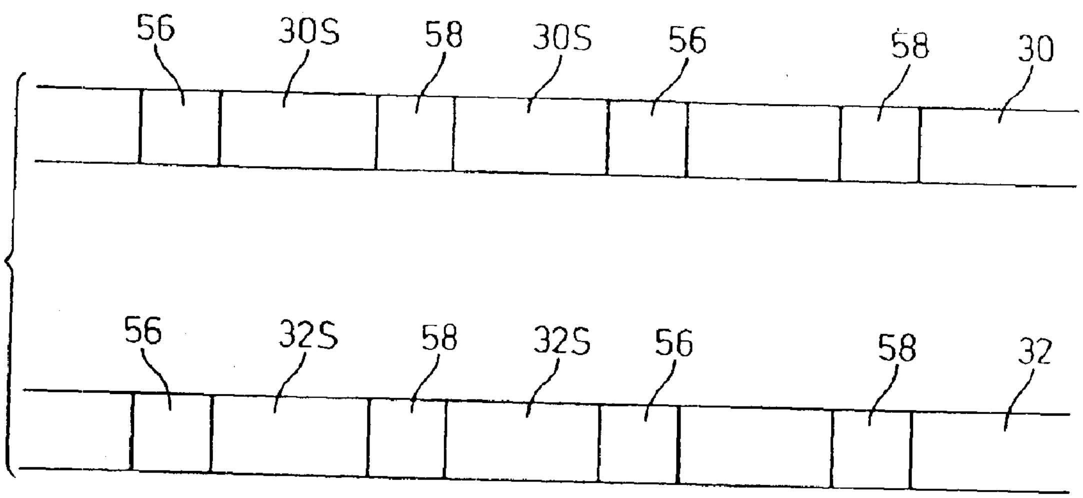

56
30S
58
30S
56
58
30
56
32S
58
32S
56
58
32

Fig. 34

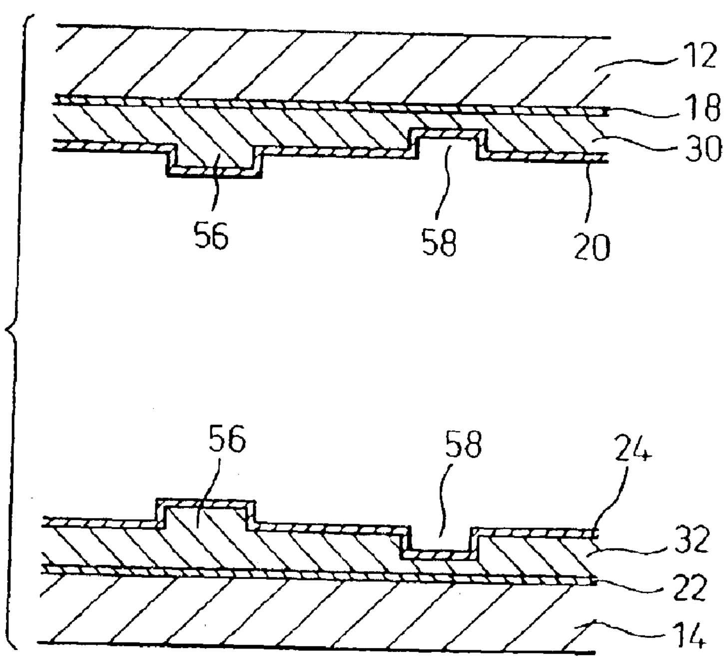

12
18
30
56
58
20
56
58
24
32
22
14

Fig. 35A

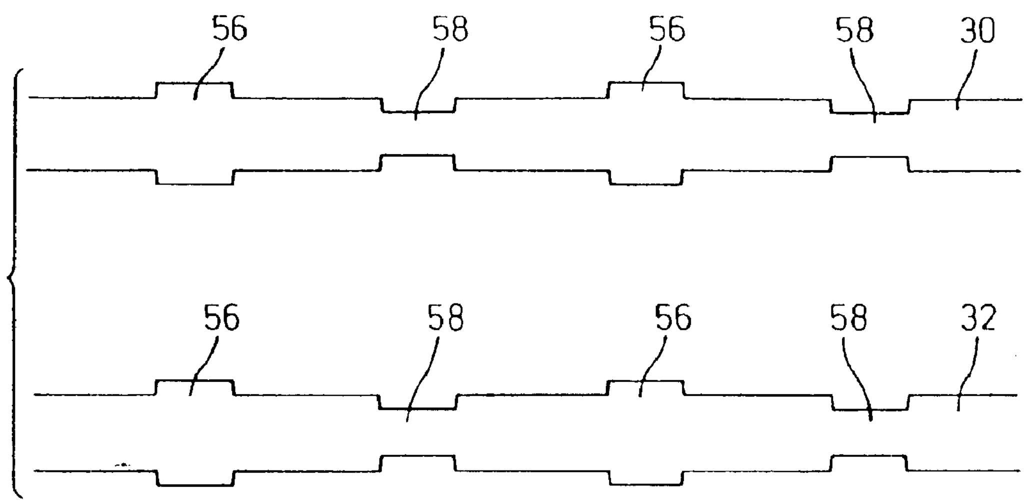


Fig. 35B

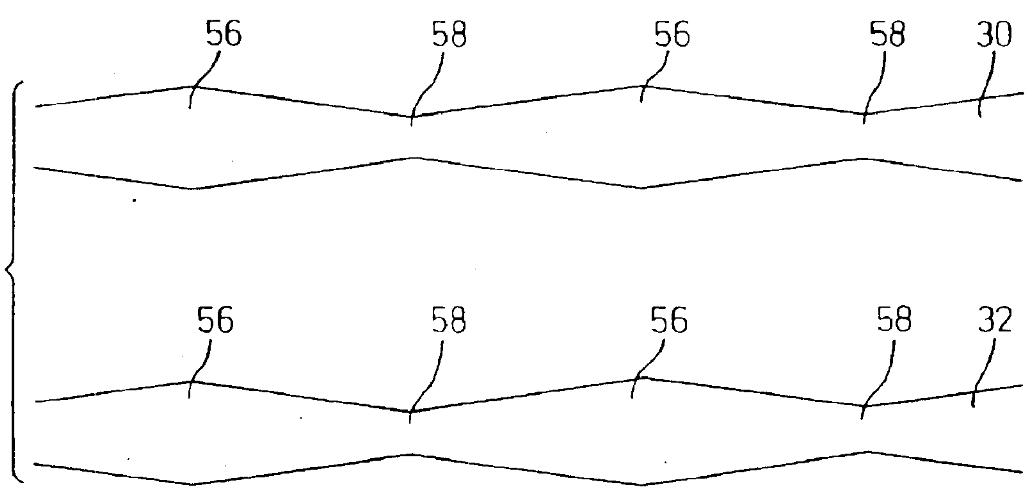


Fig. 36

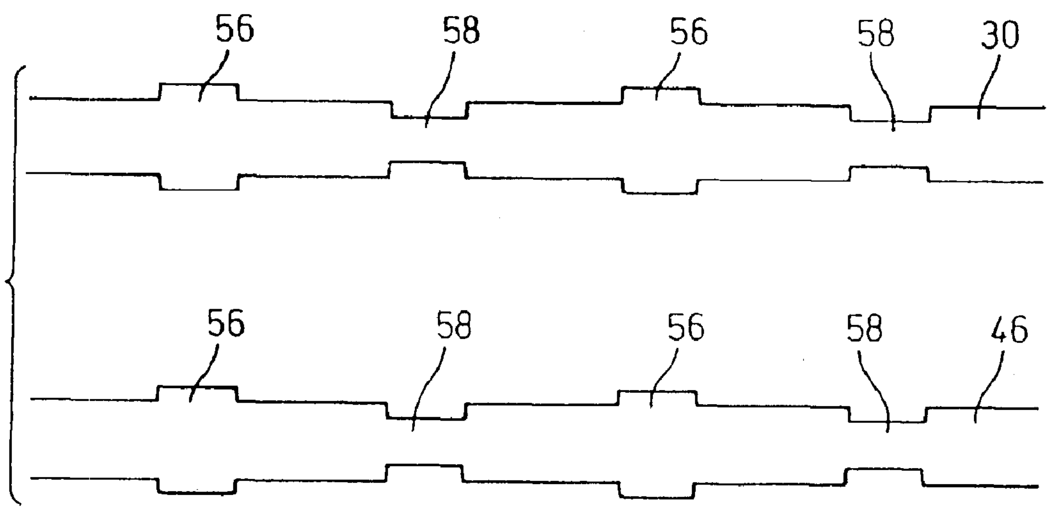


Fig. 37

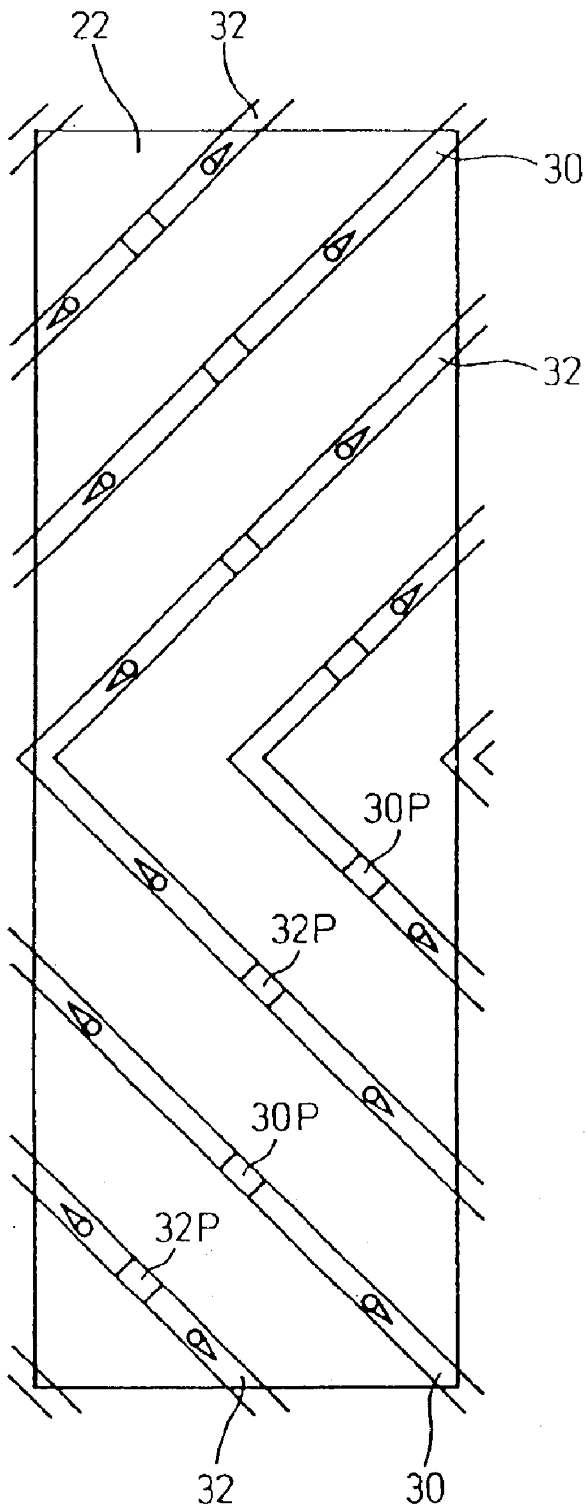


Fig.38A

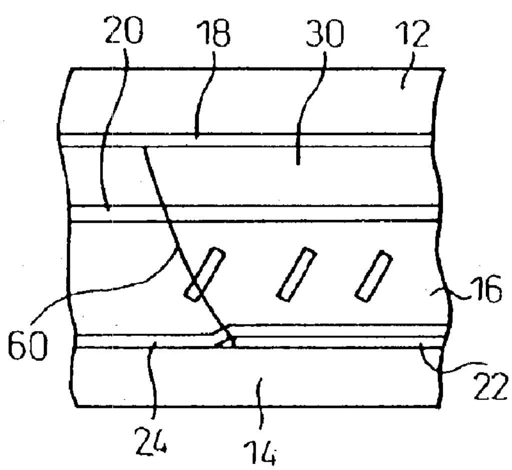


Fig.38B

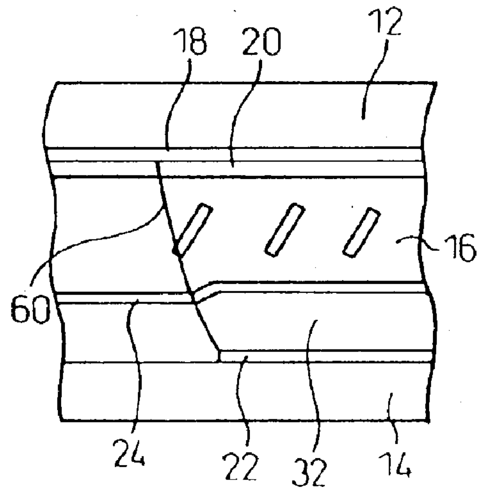


Fig.39A

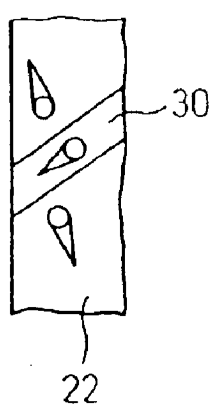


Fig.39B

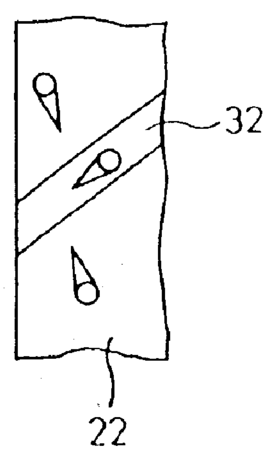


Fig. 40

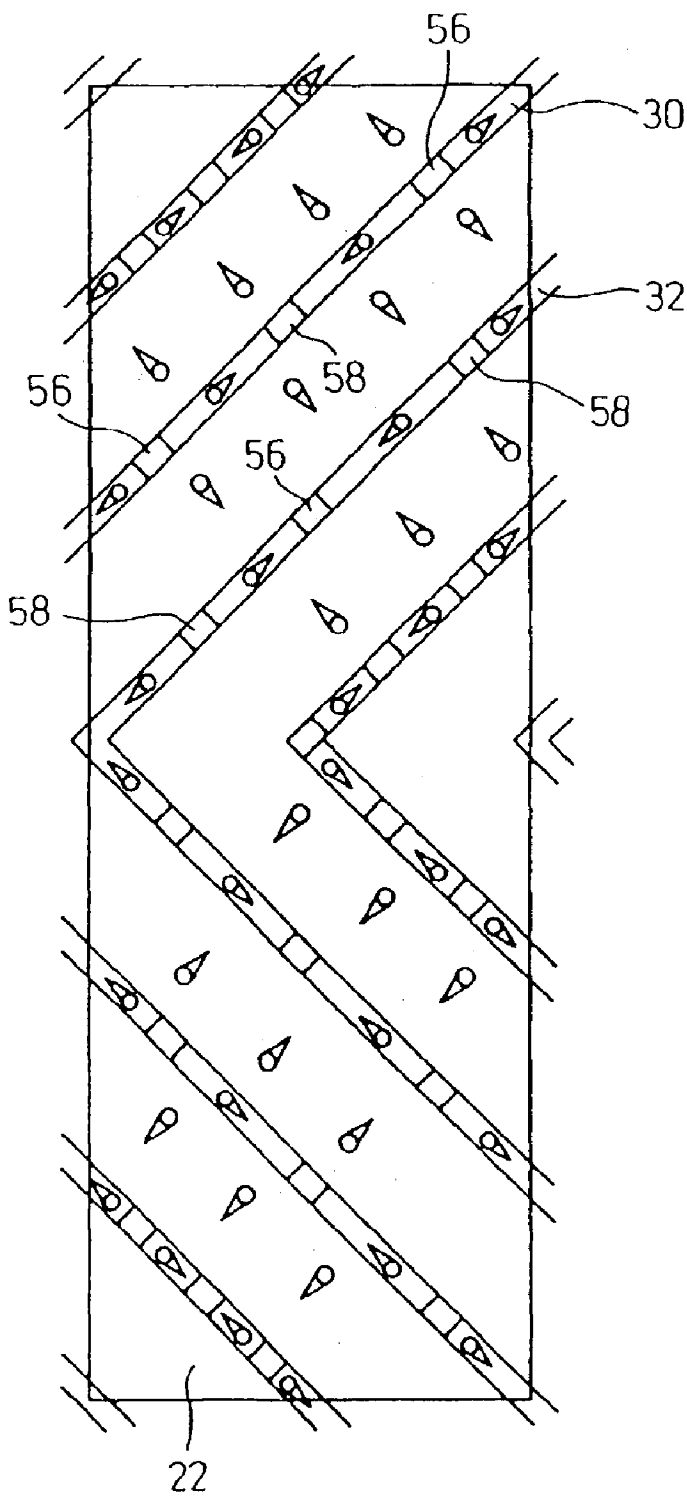


Fig. 41

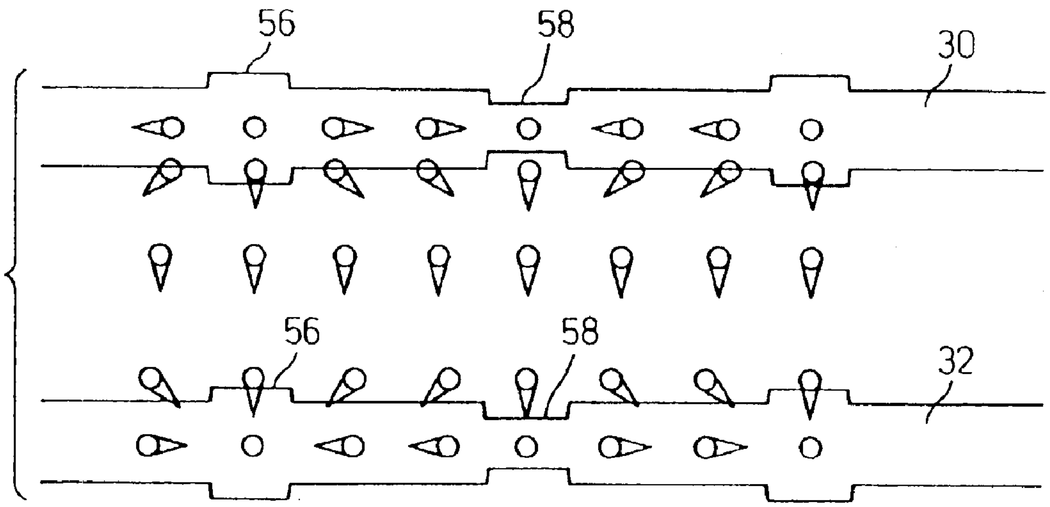


Fig. 42

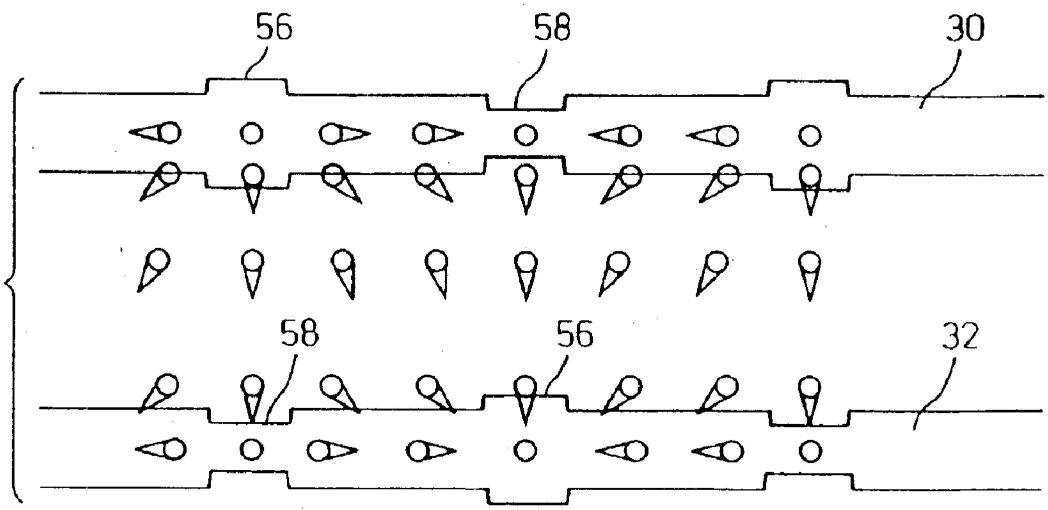


Fig. 43

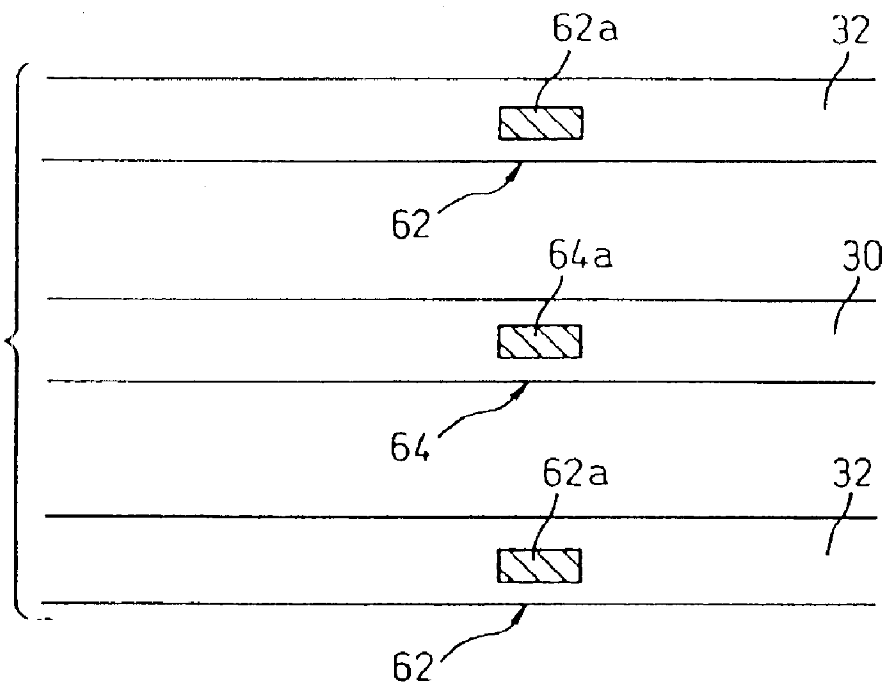


Fig. 44

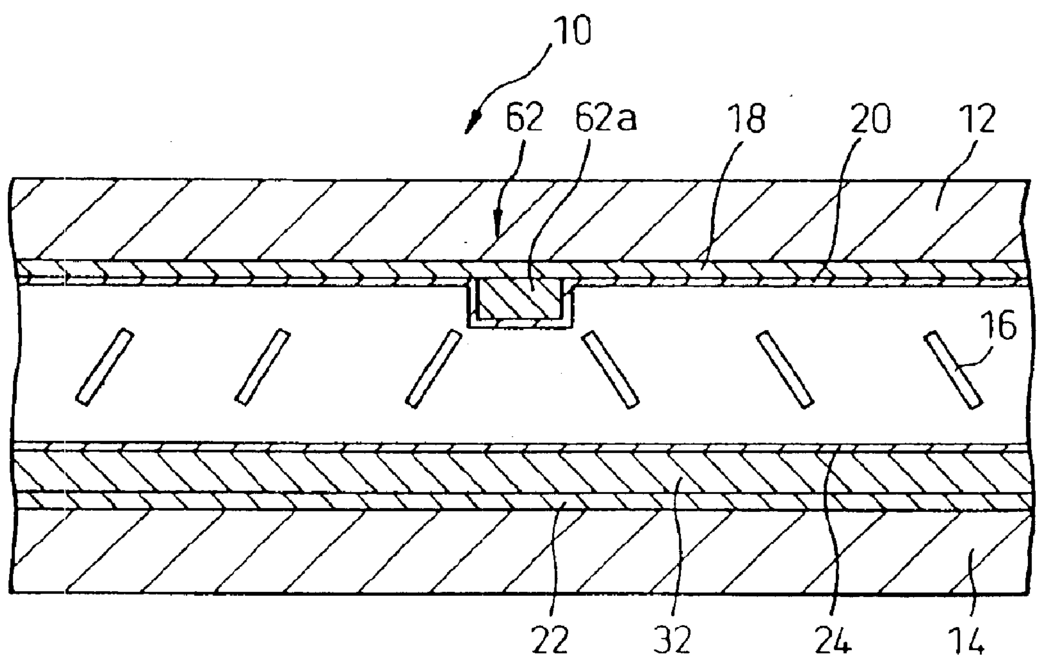


Fig. 45

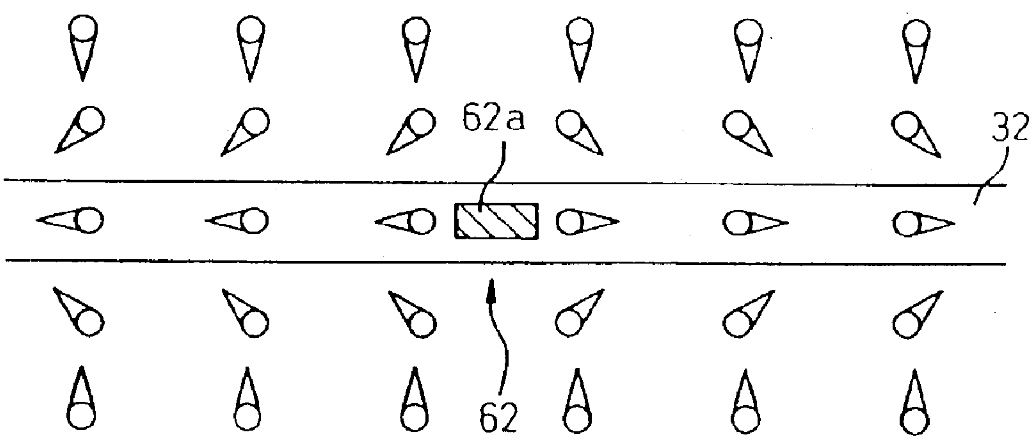


Fig. 46

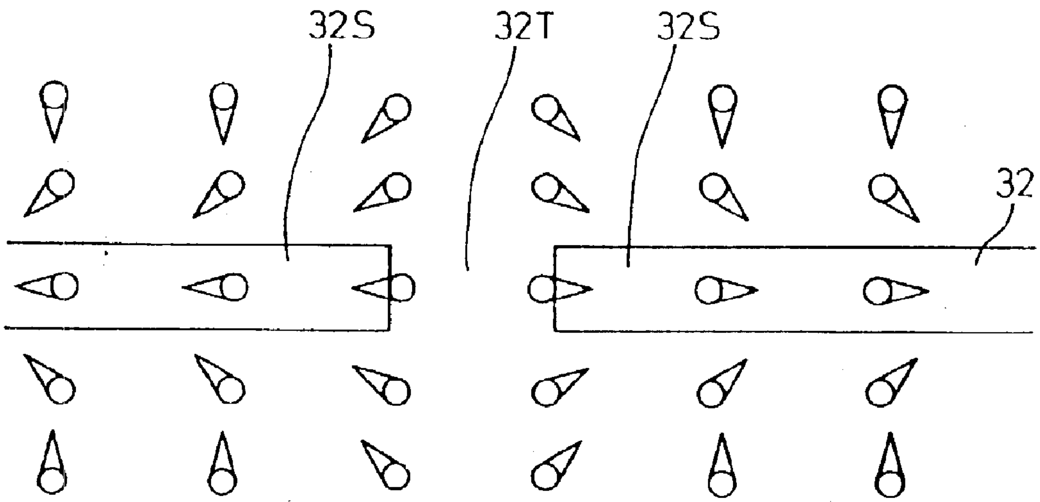


Fig. 47A

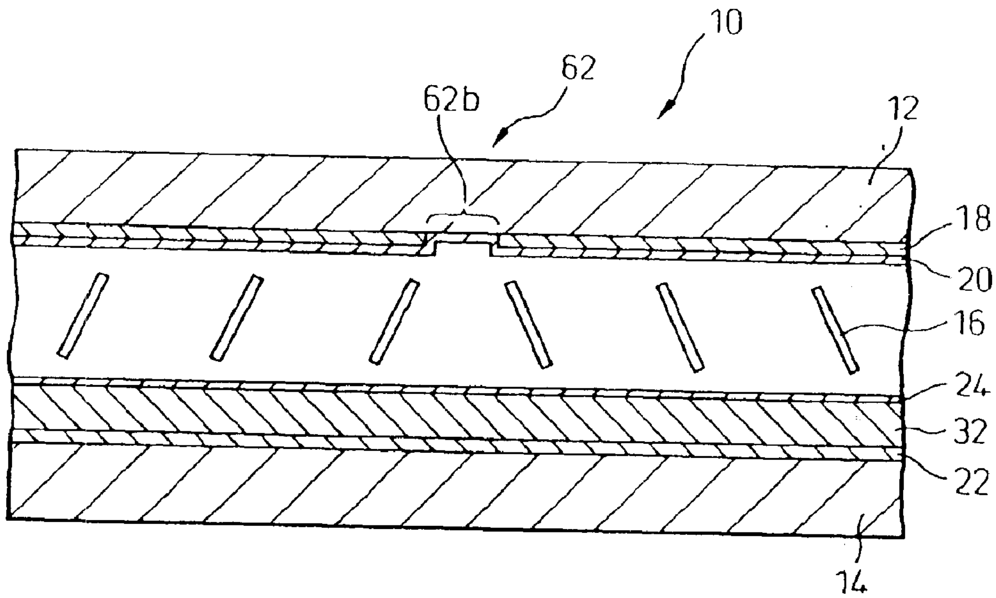


Fig. 47B

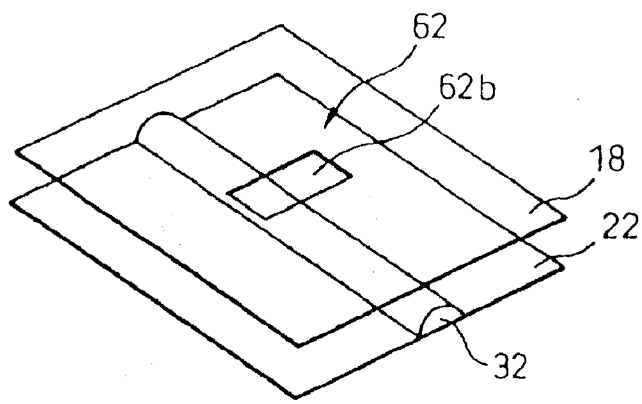


Fig. 47C

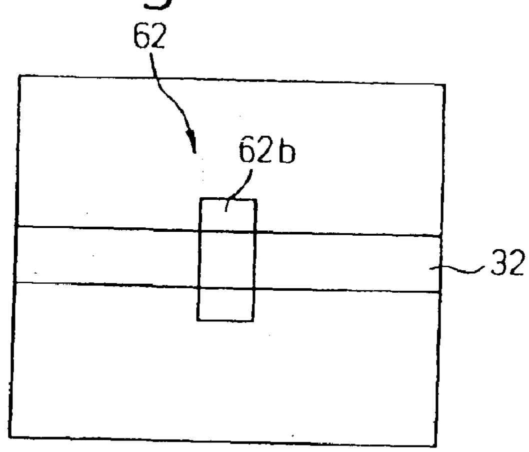


Fig. 48

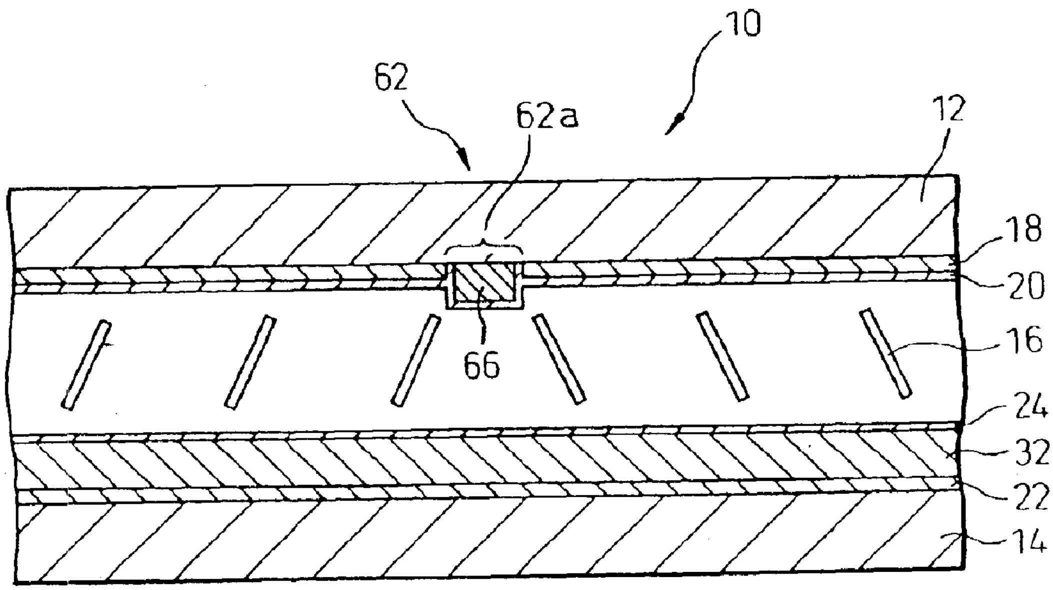


Fig. 49

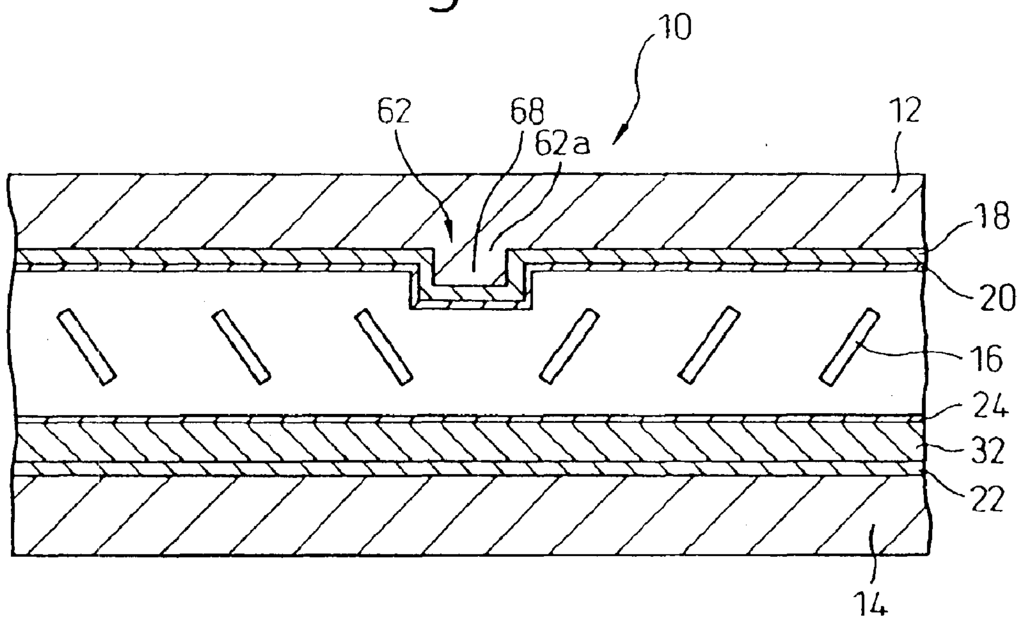


Fig. 50

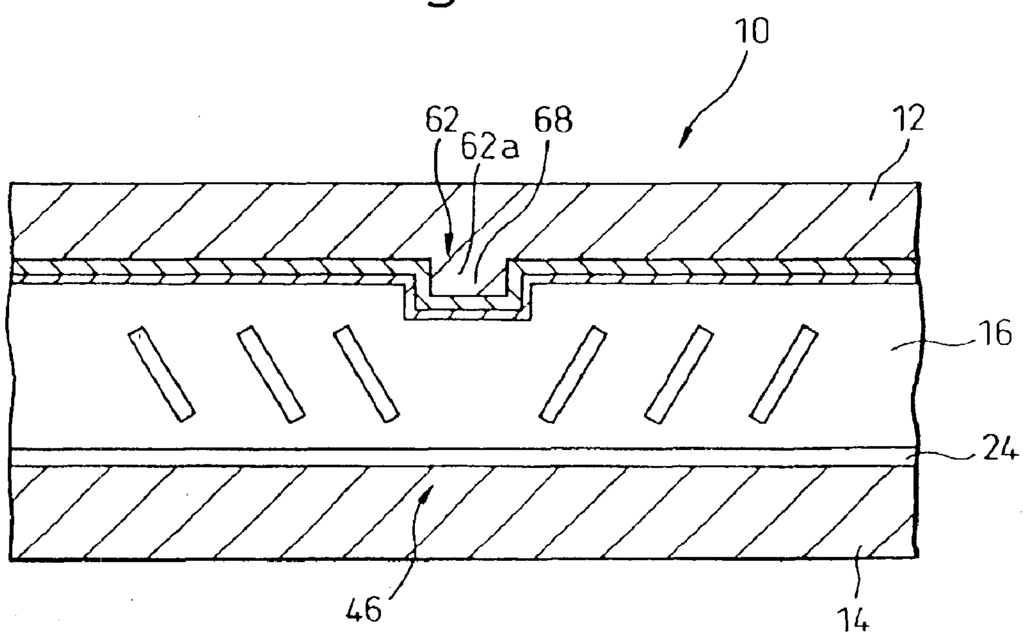


Fig. 51

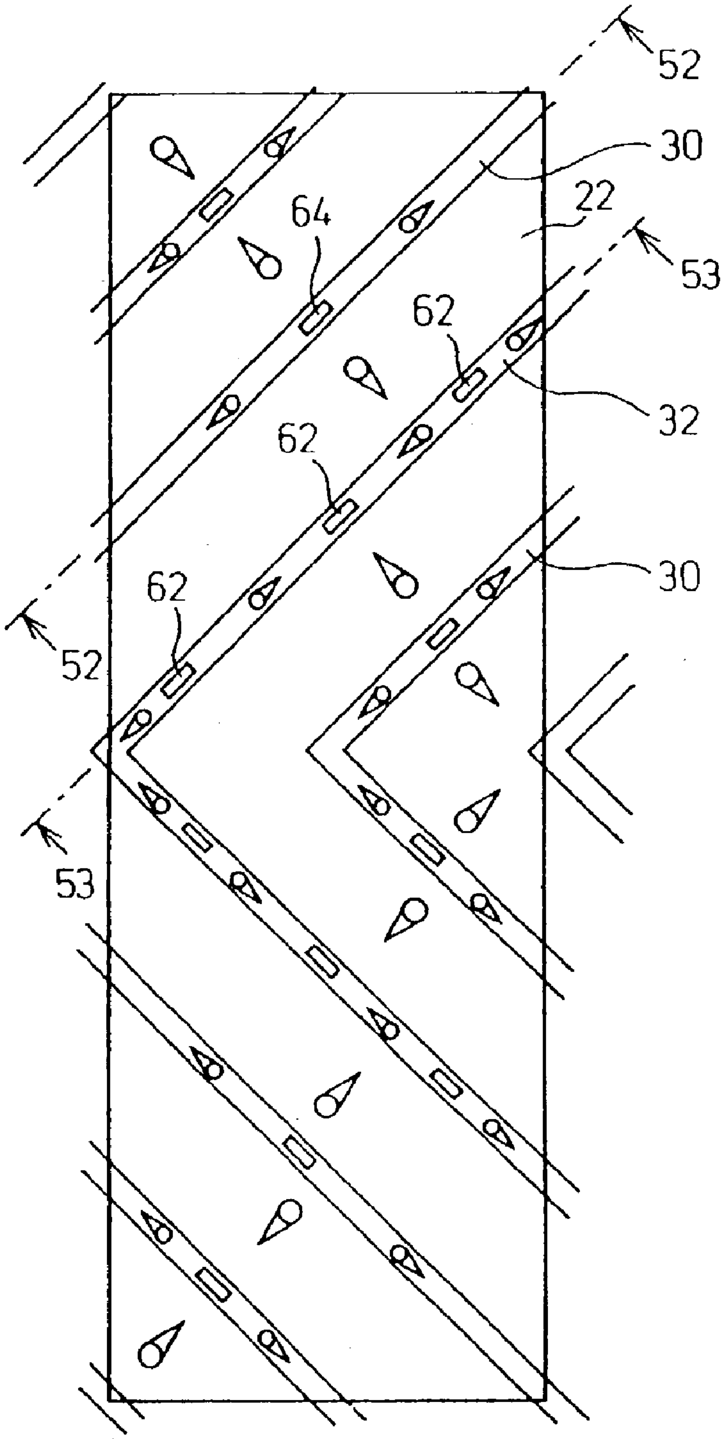


Fig. 52

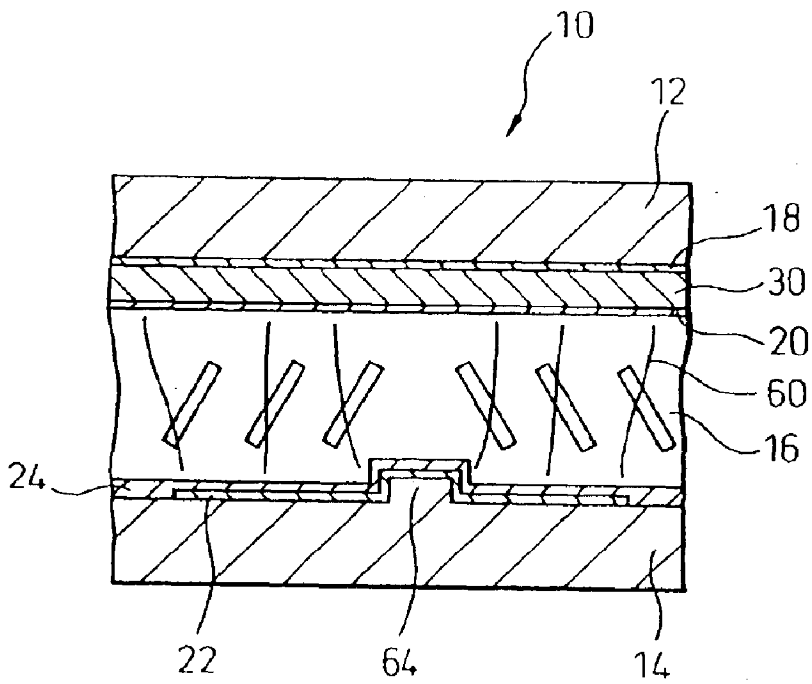

10
12
18
30
20
60
16
24
22
64
14

Fig. 53

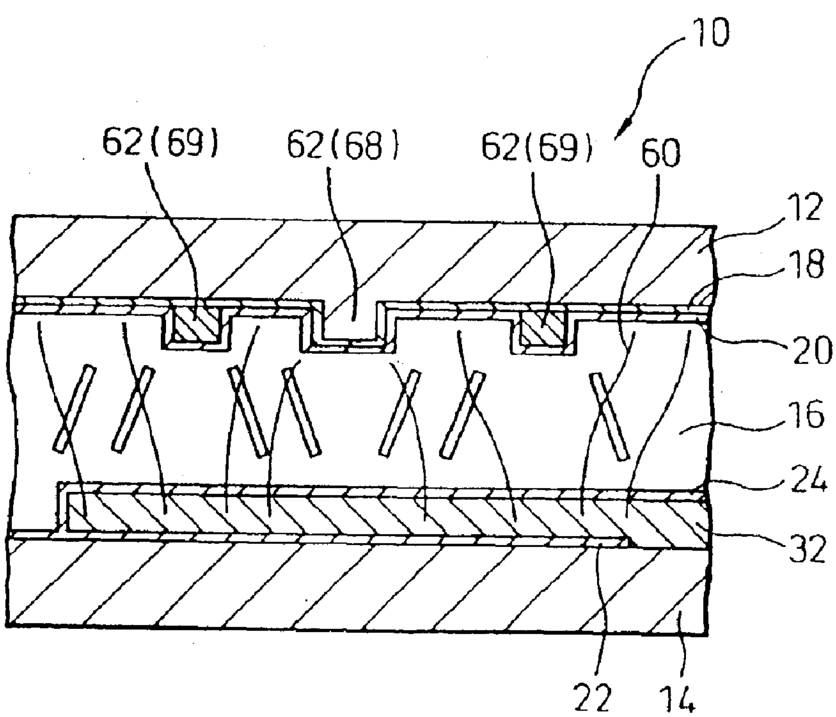

10
62(69)
62(68)
62(69)
60
12
18
20
16
24
32
22
14

Fig. 54

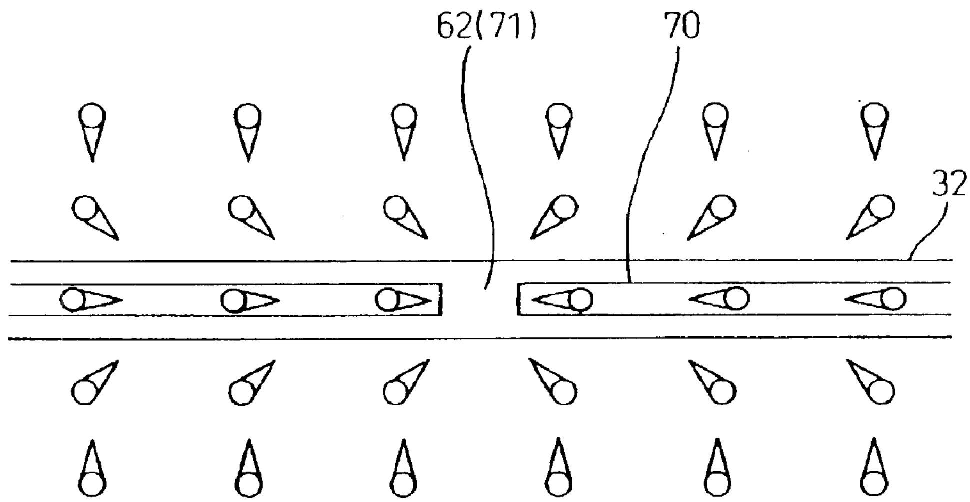


Fig. 55

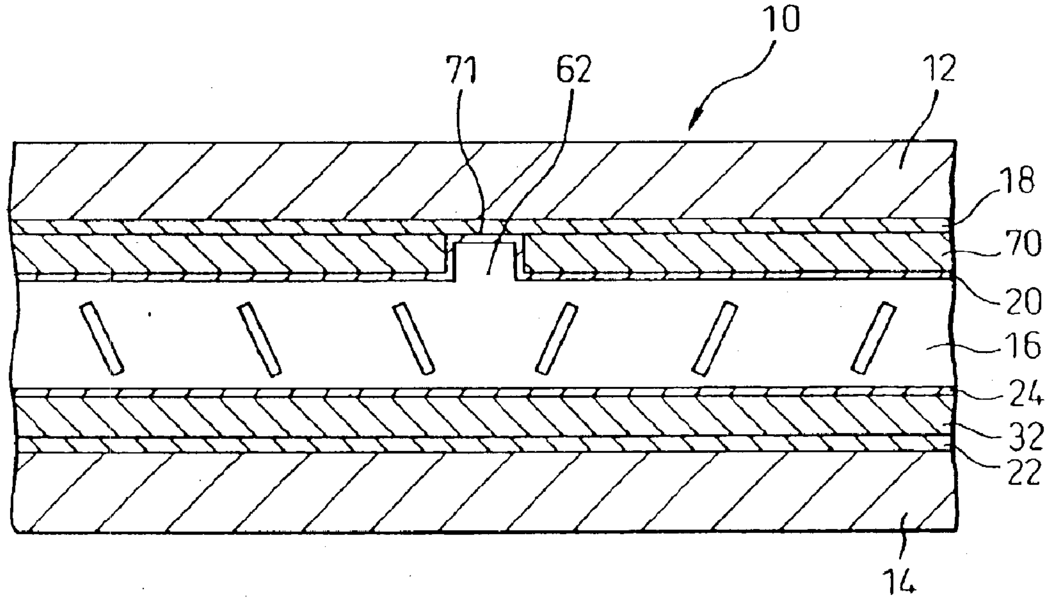


Fig. 56

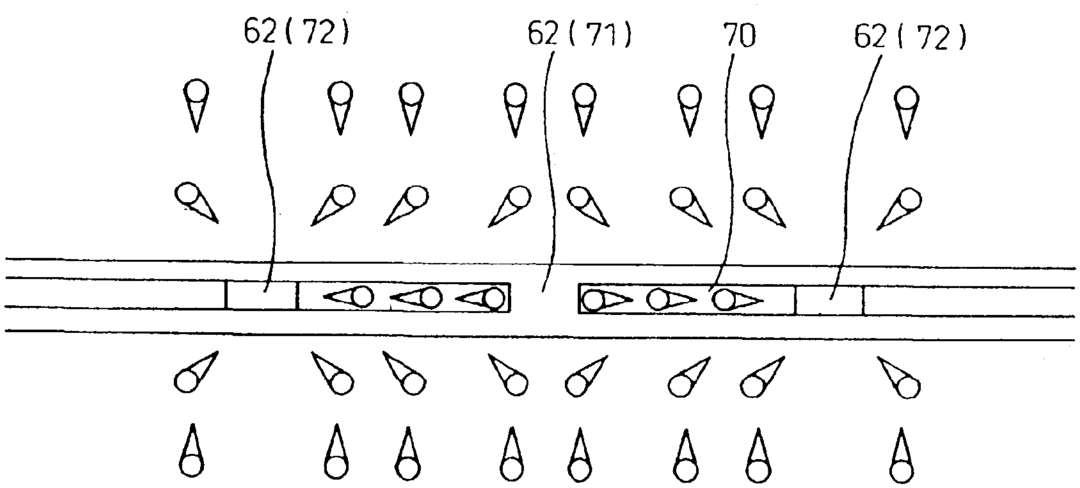


Fig. 57

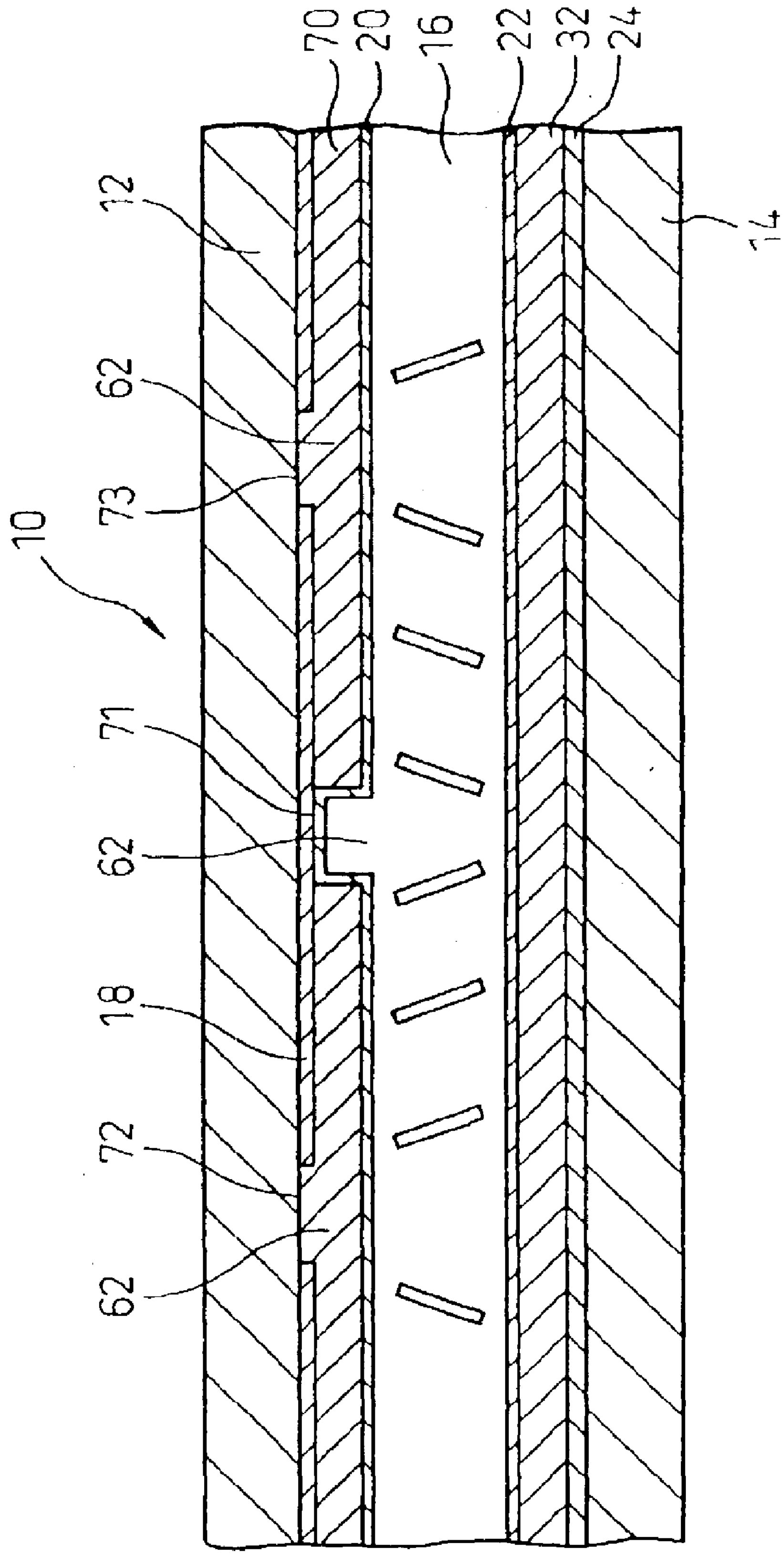


Fig. 58

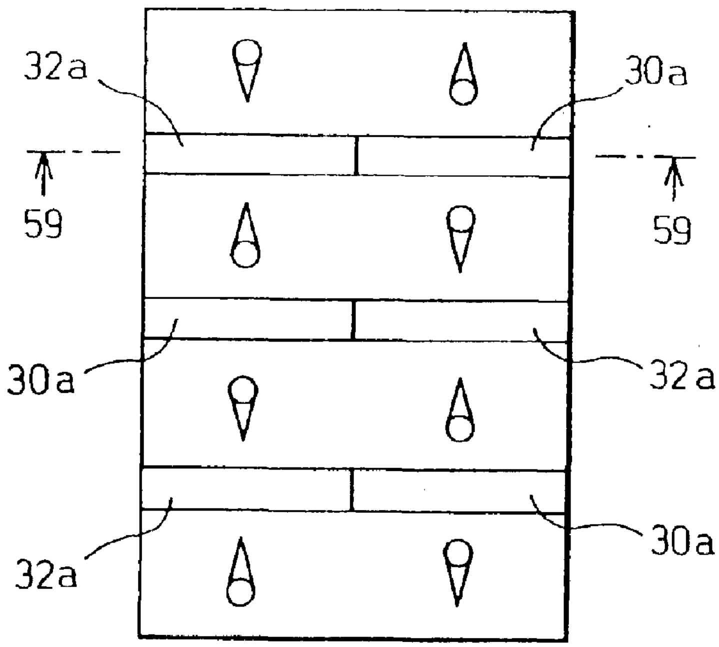


Fig. 59

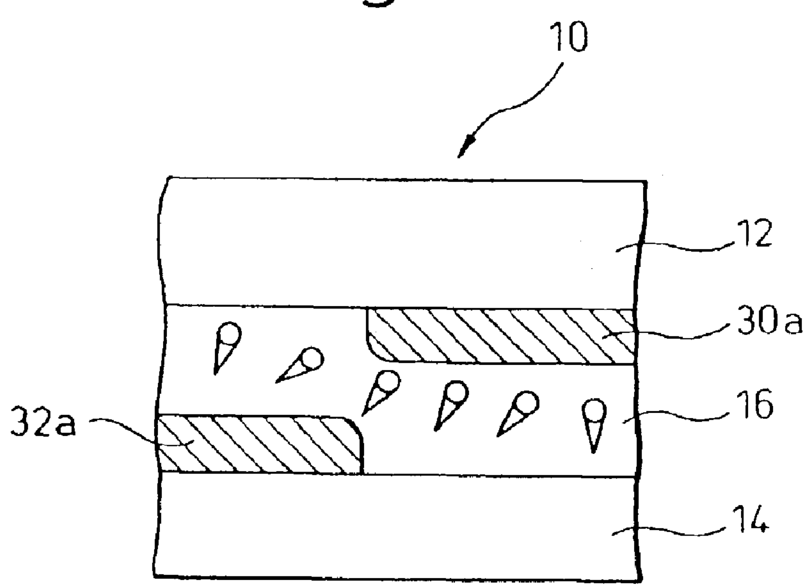


Fig. 60

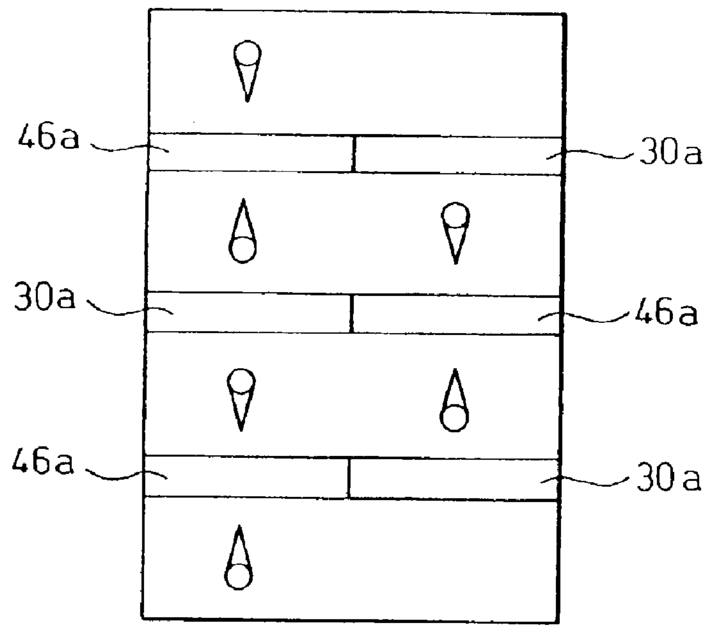


Fig. 61

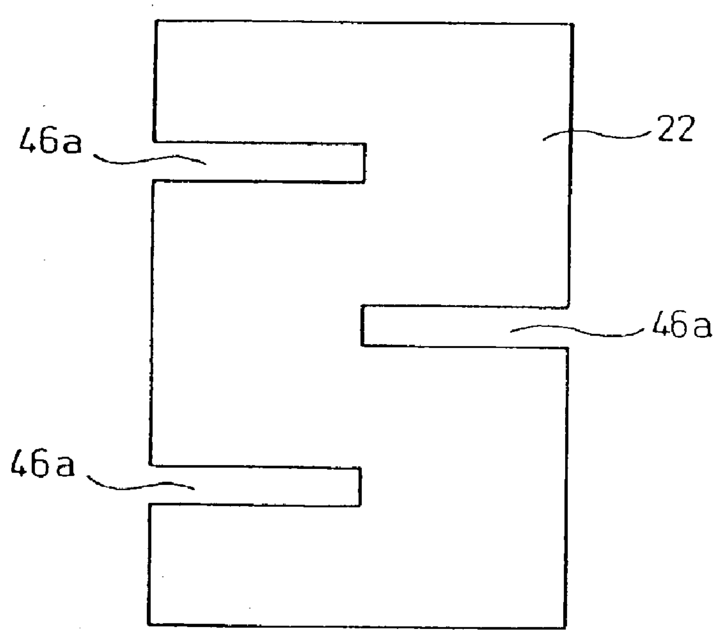


Fig. 62

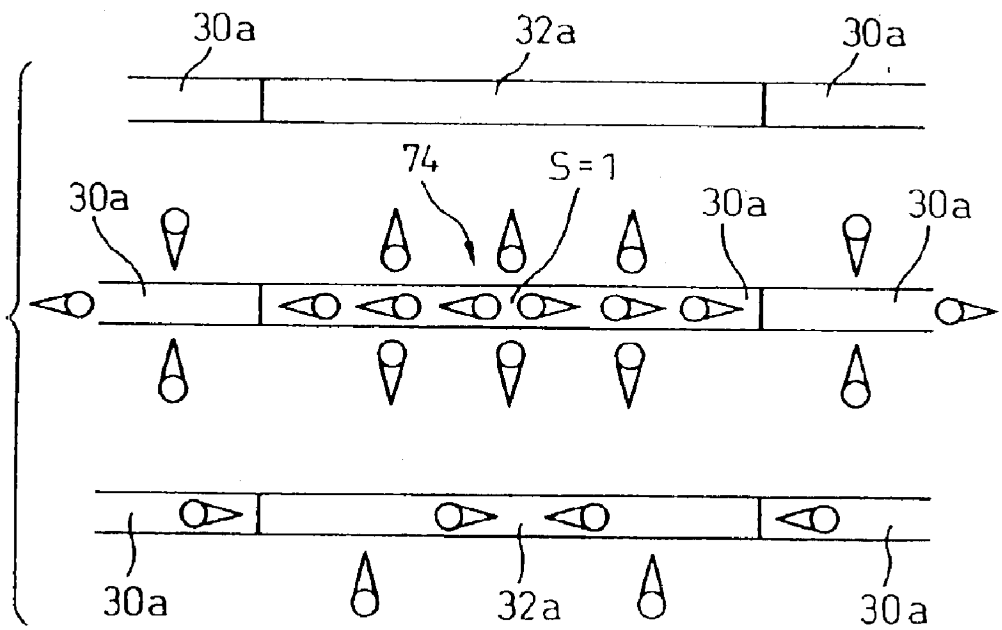

30a
32a
30a
74
S=1
30a
30a
30a
30a
32a
30a

Fig. 63

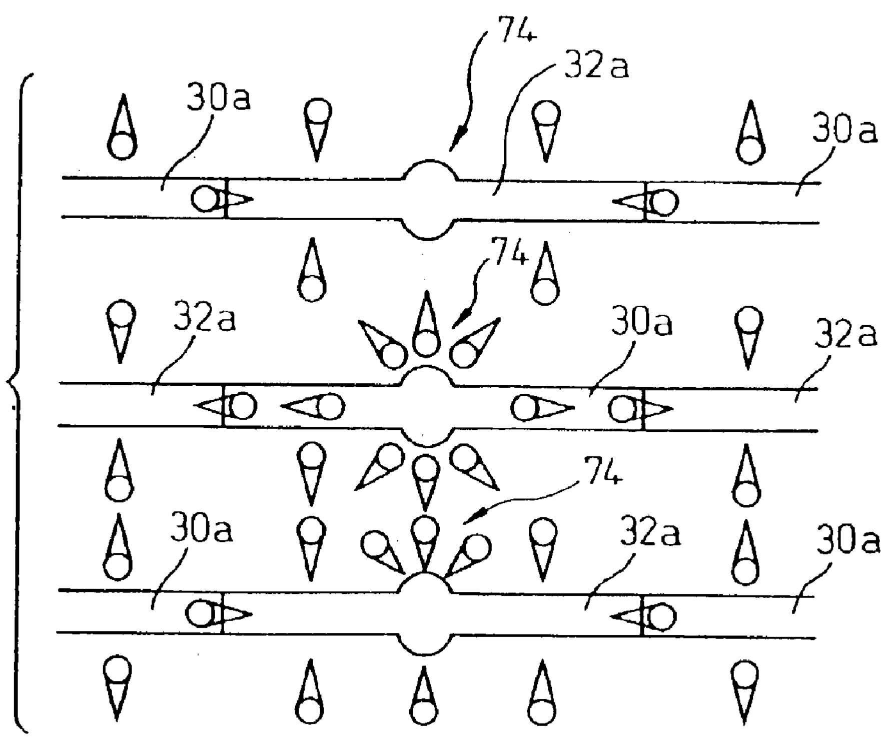

74
32a
30a
30a
74
32a
30a
32a
74
30a
32a
30a

Fig. 64

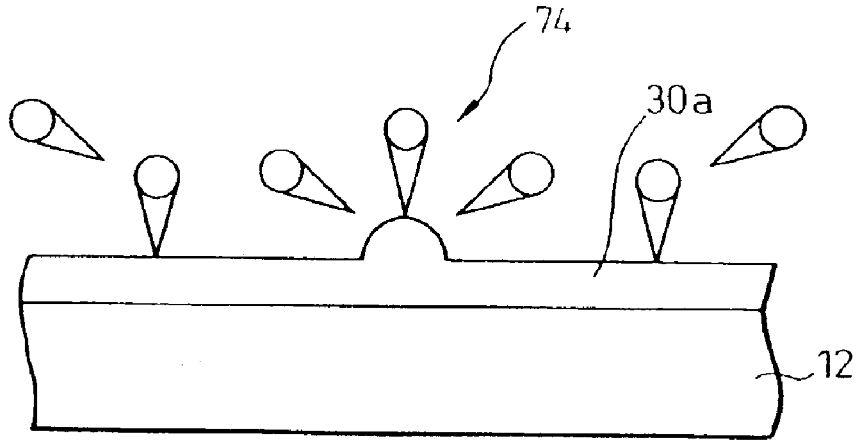


Fig. 65

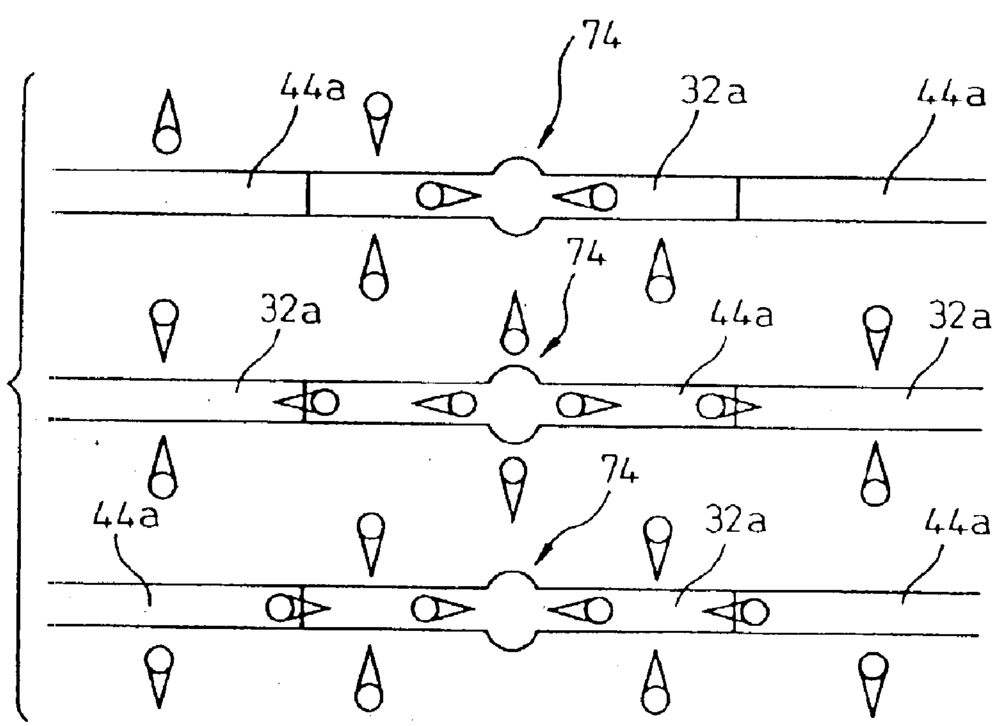


Fig. 66

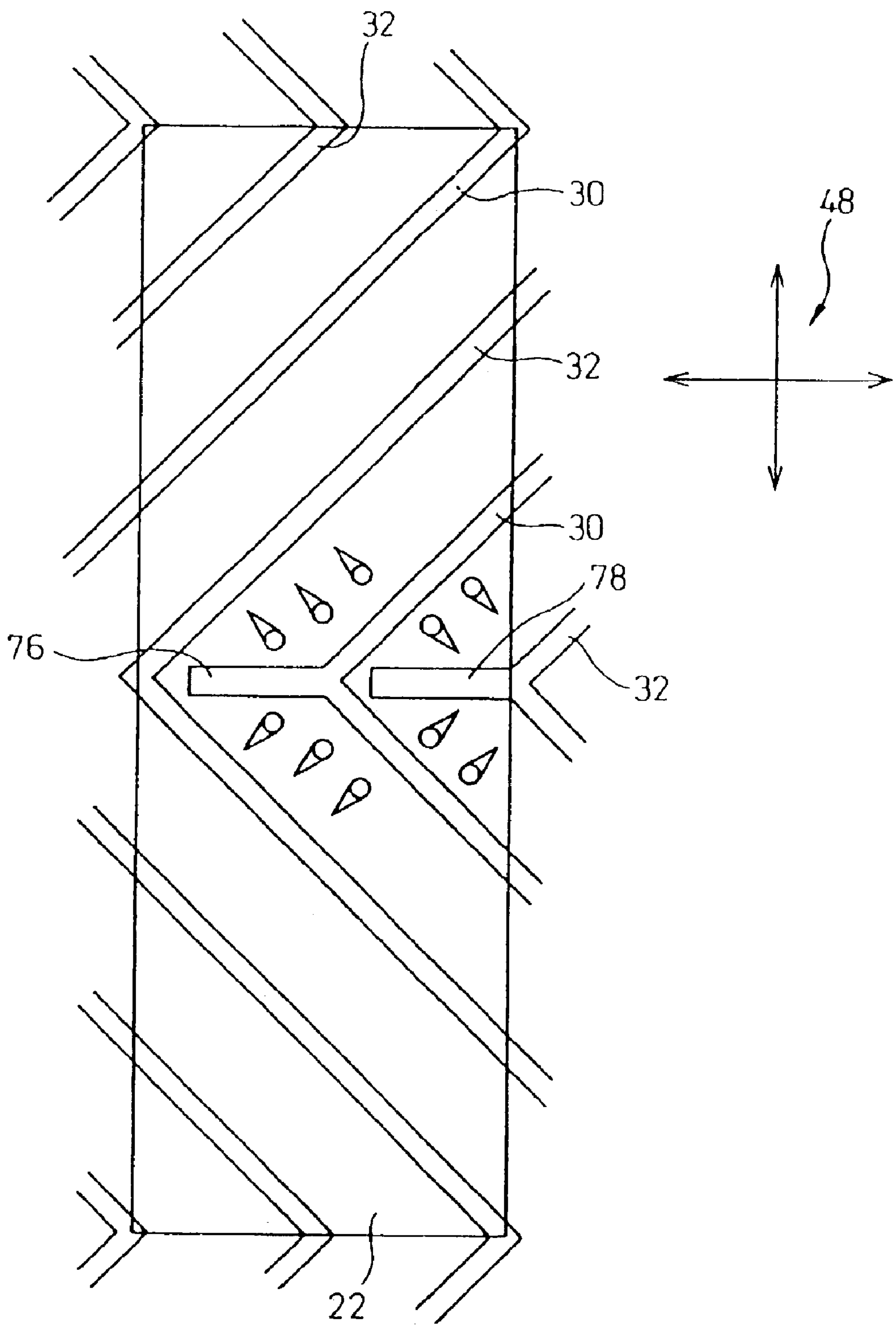
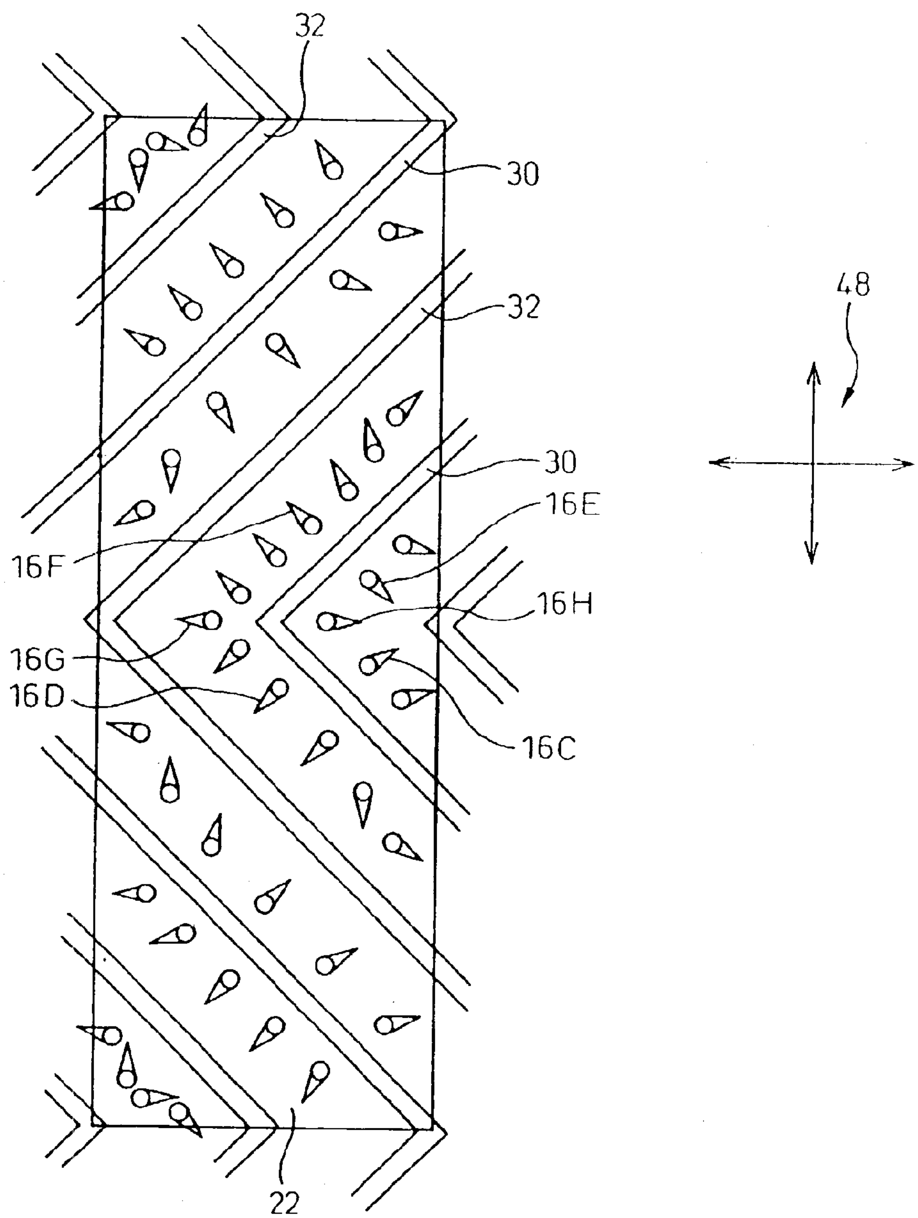


Fig. 67



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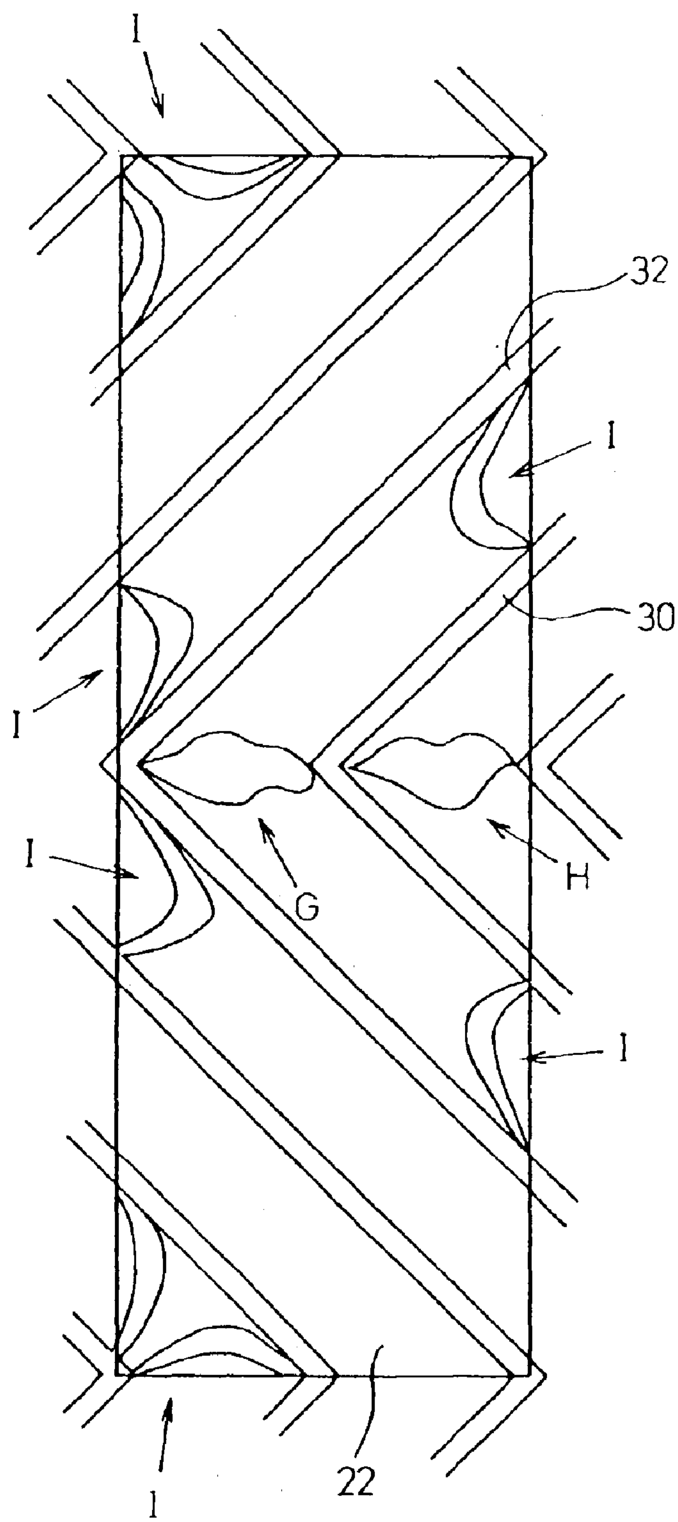

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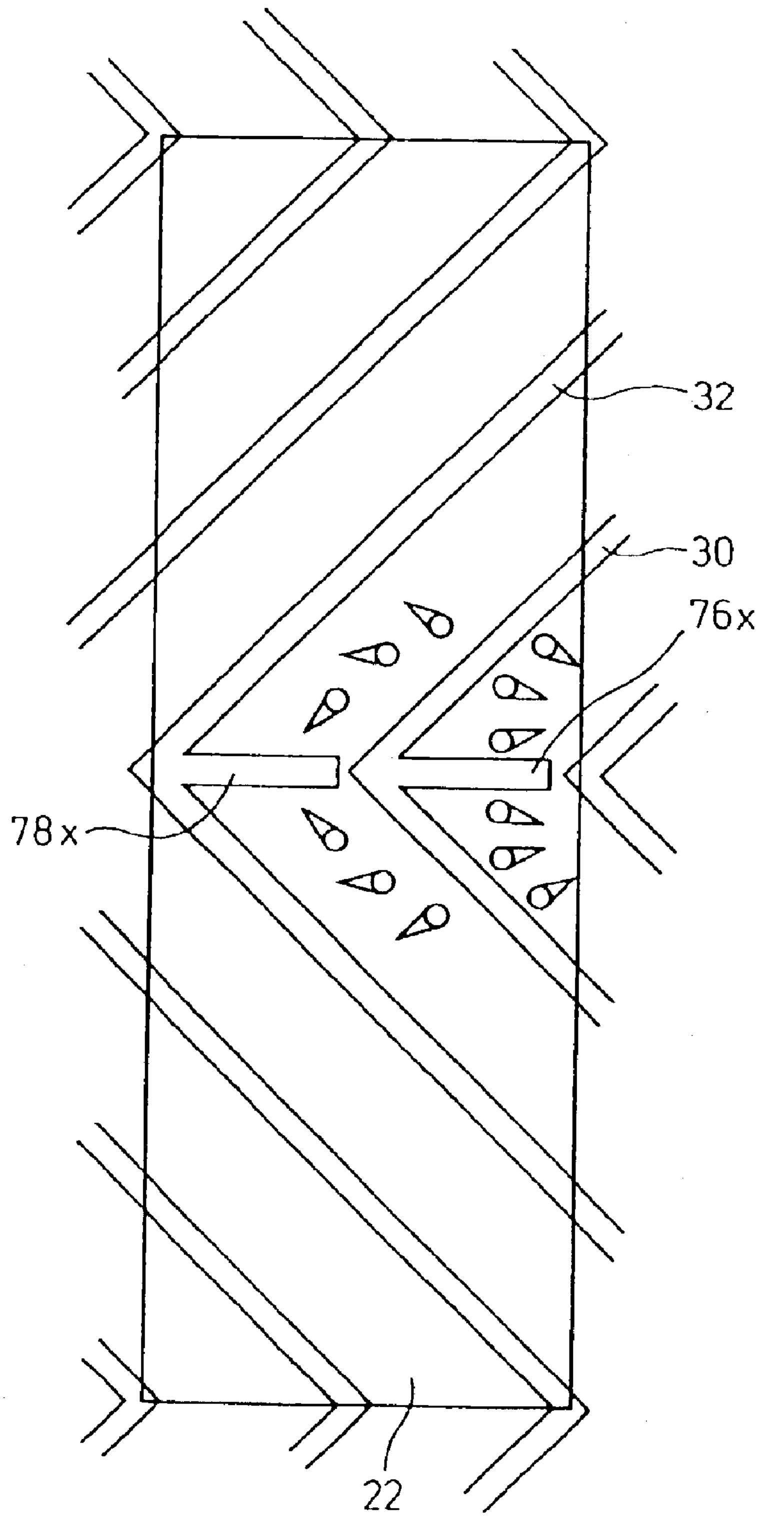

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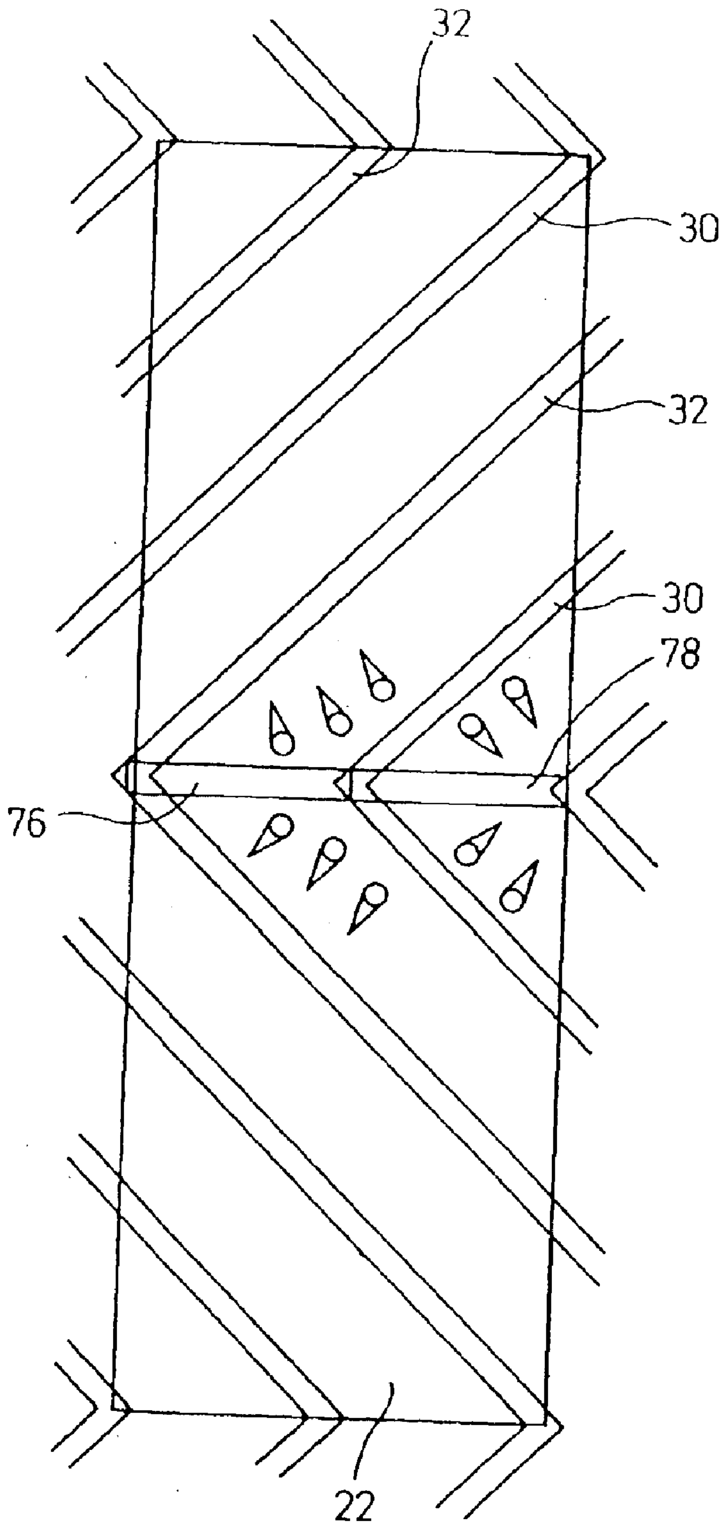

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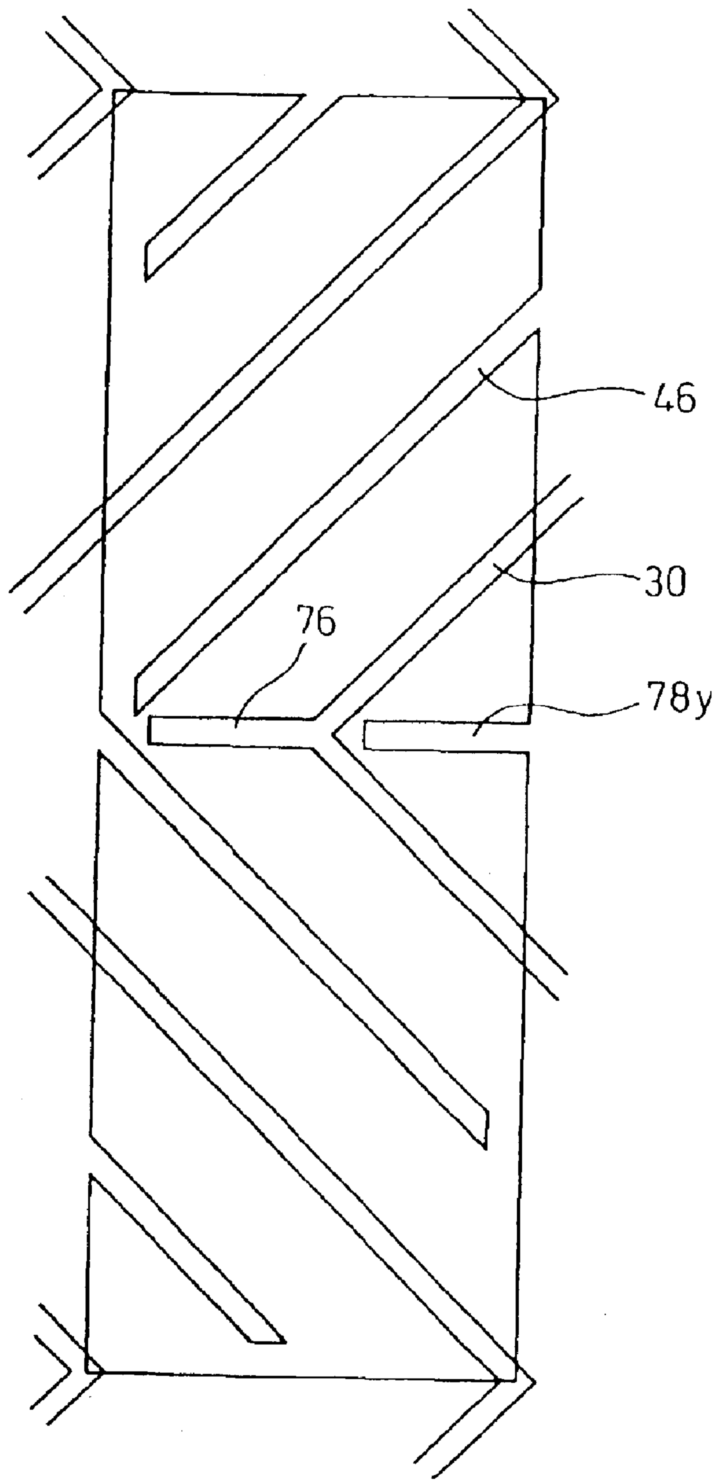

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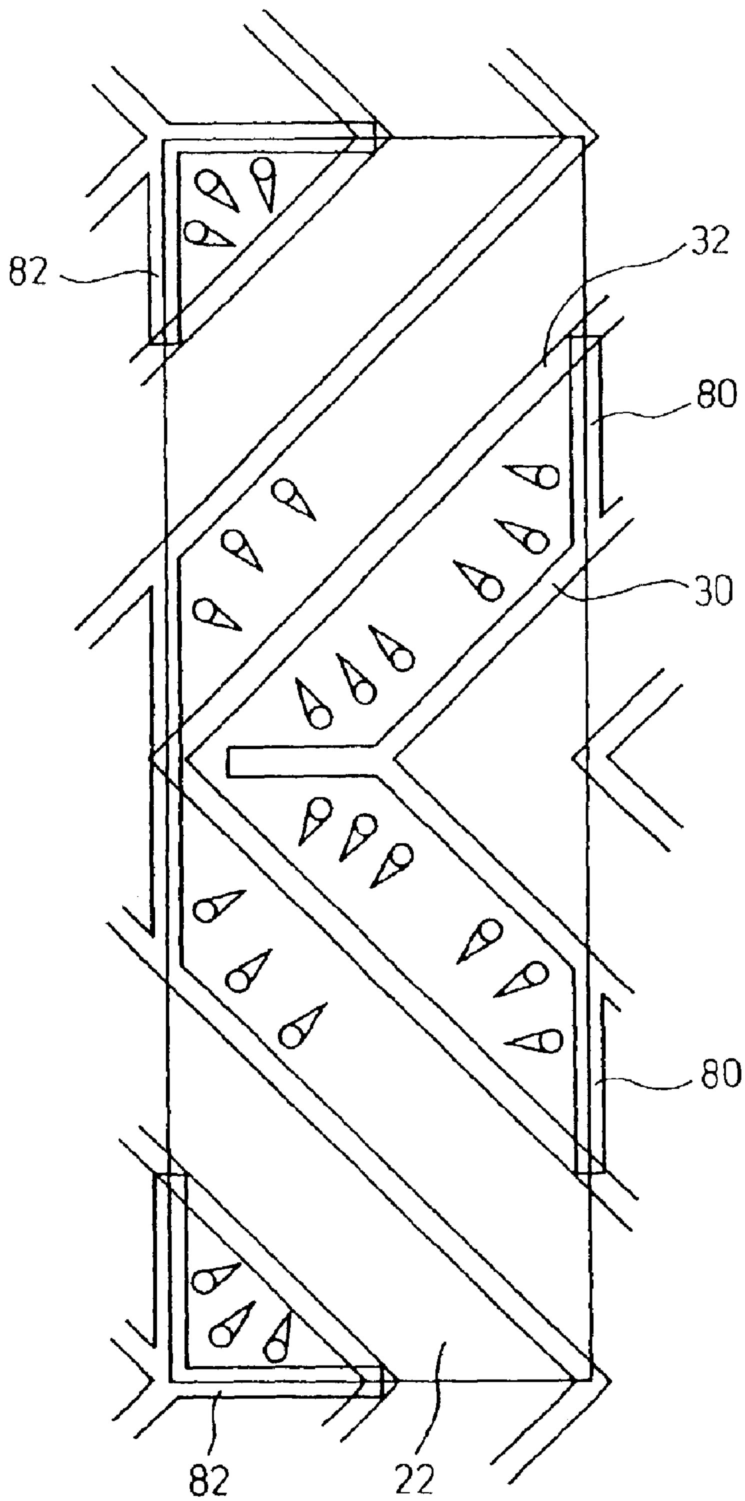
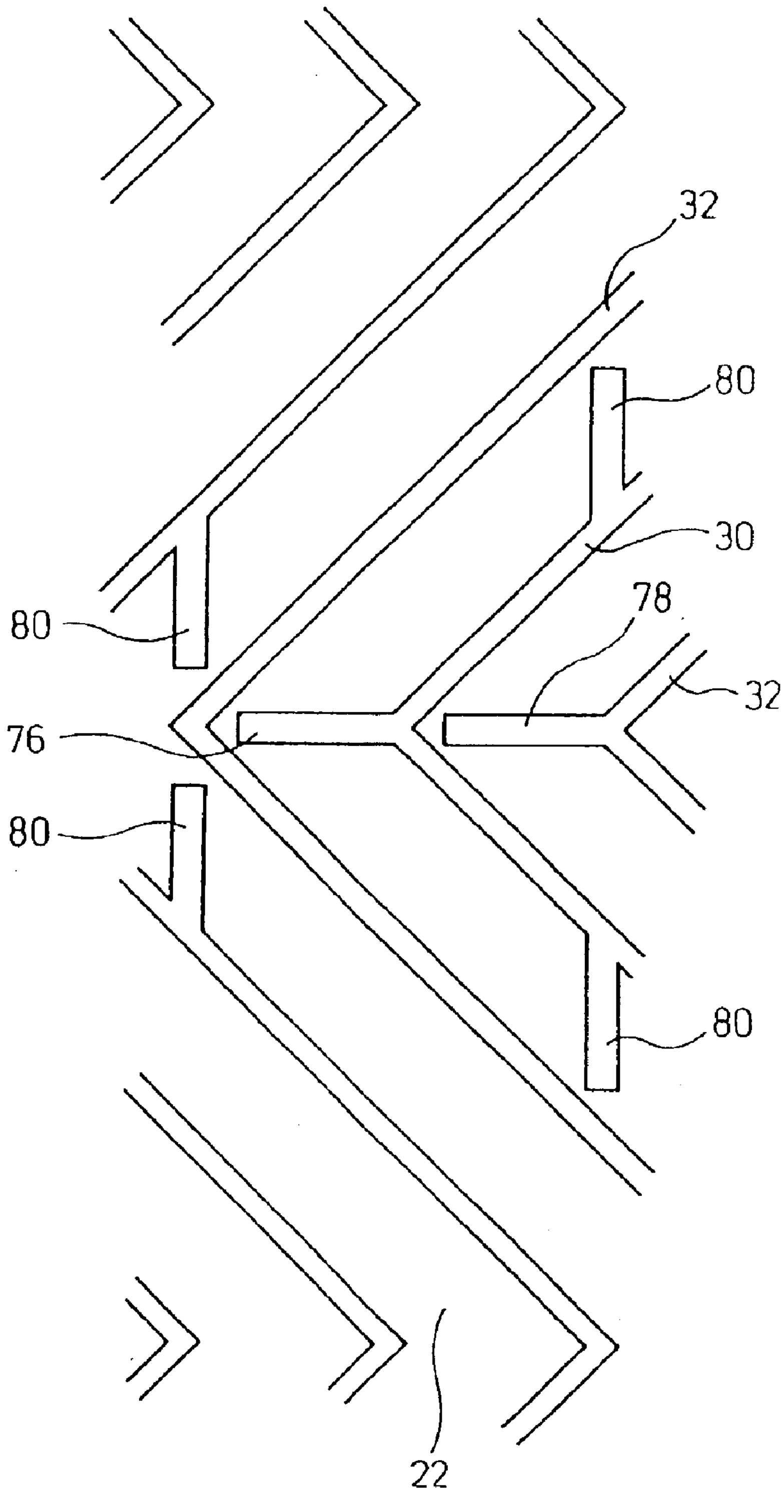


Fig. 73



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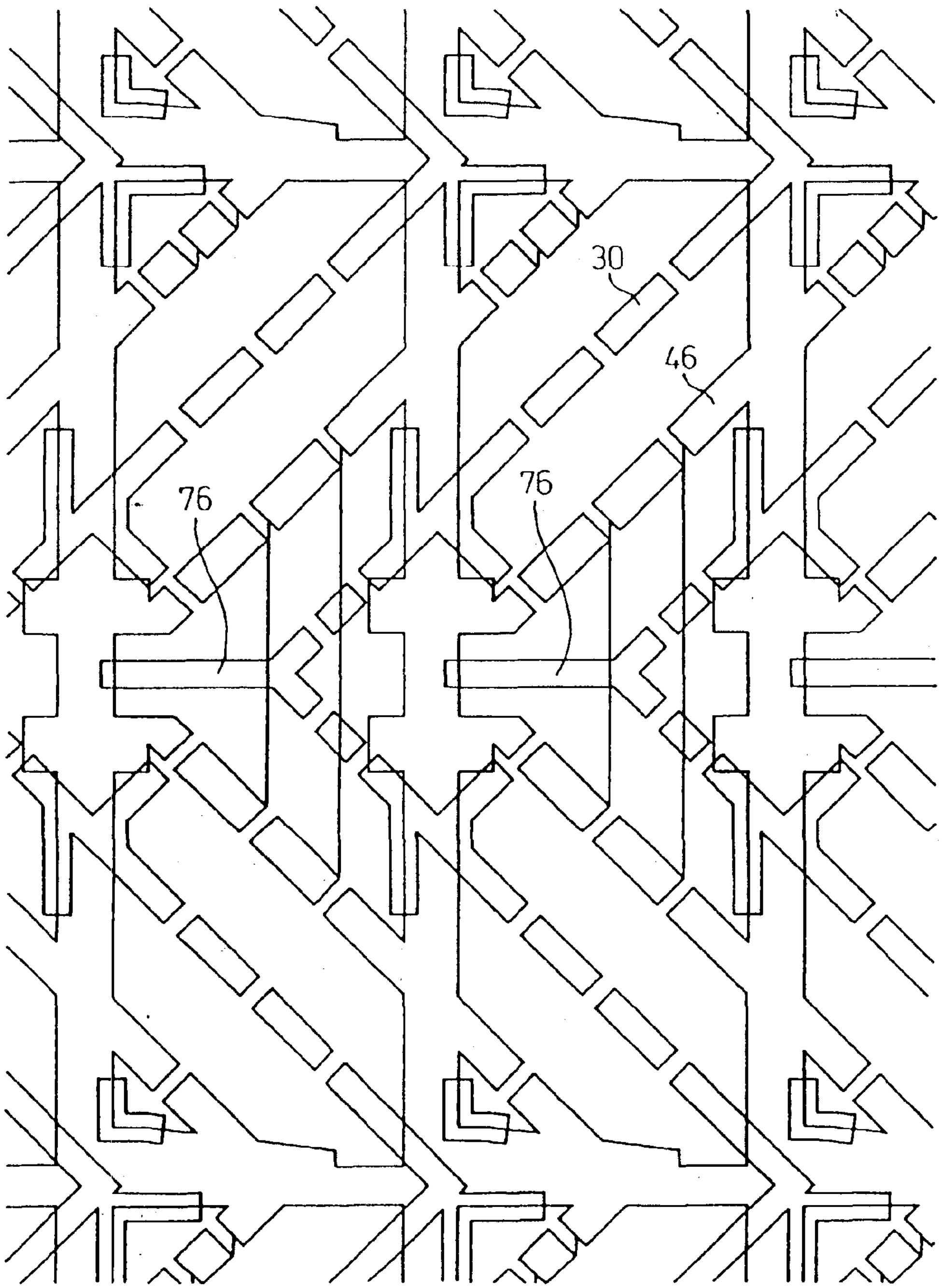

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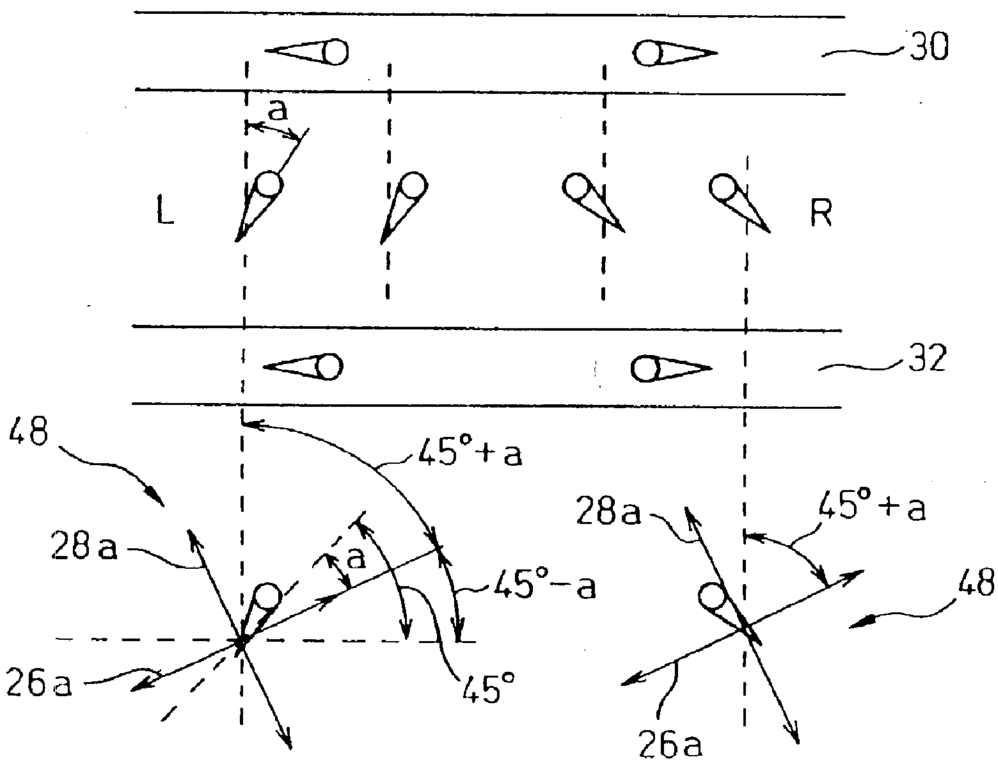


Fig.76A

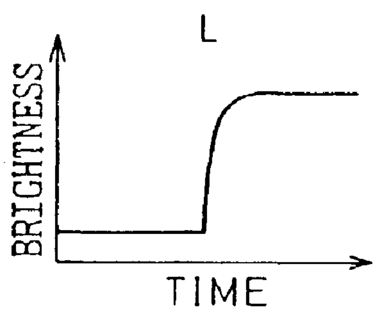


Fig.76B

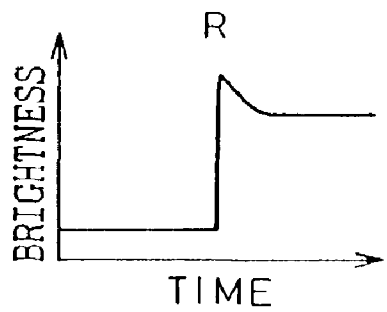


Fig.76C

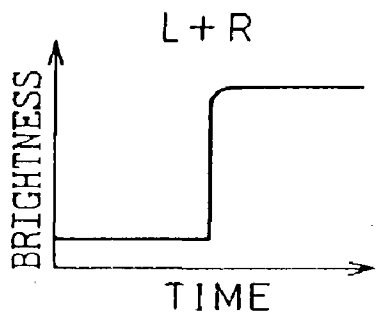
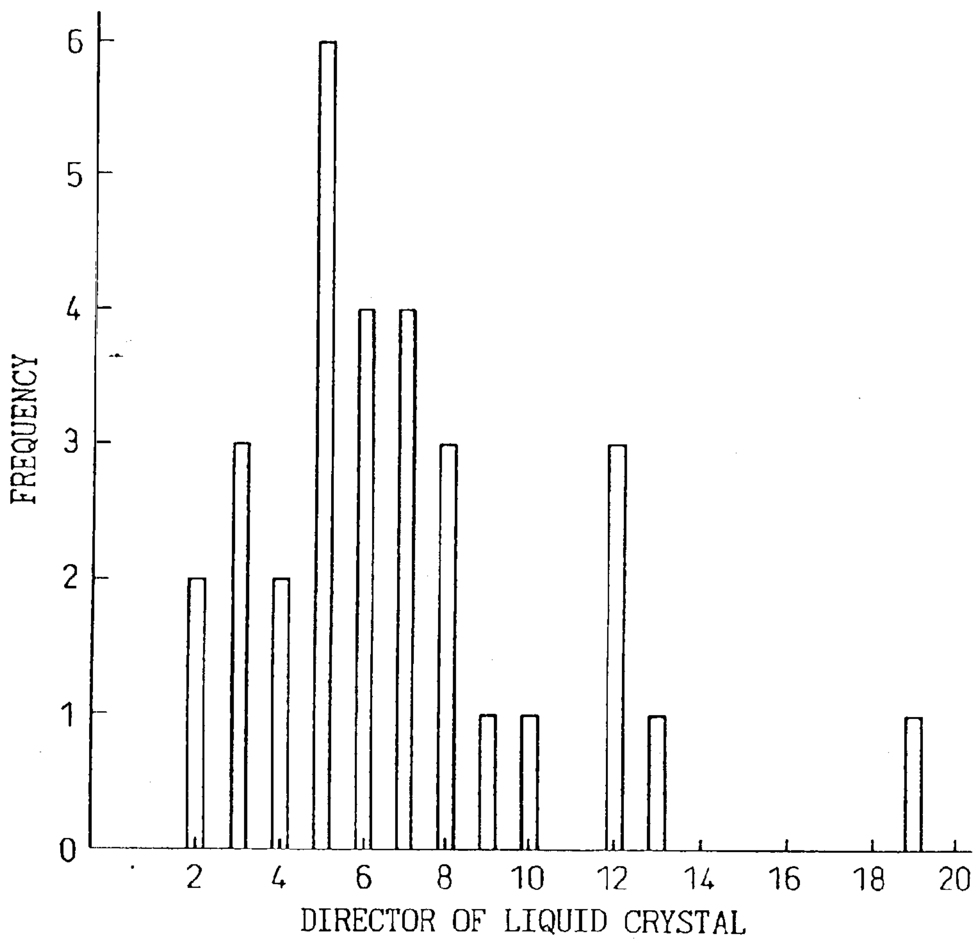


Fig. 77



FREQUENCY
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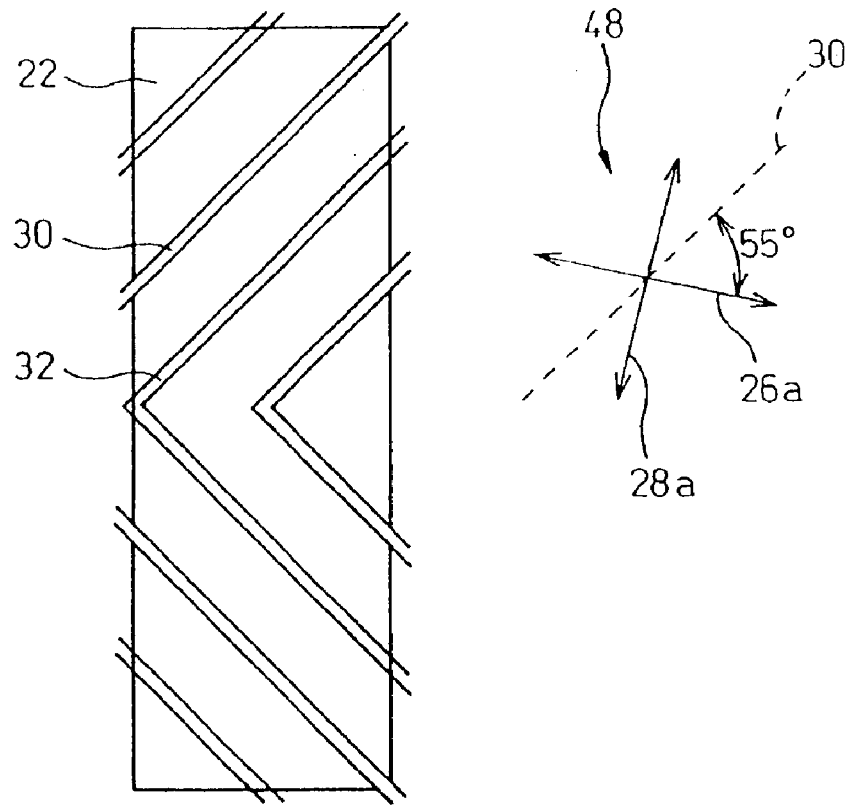
DIRECTOR OF LIQUID CRYSTAL

Fig. 78



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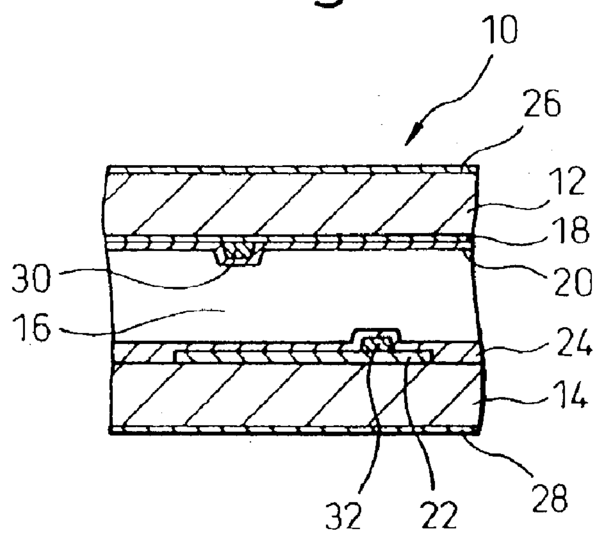

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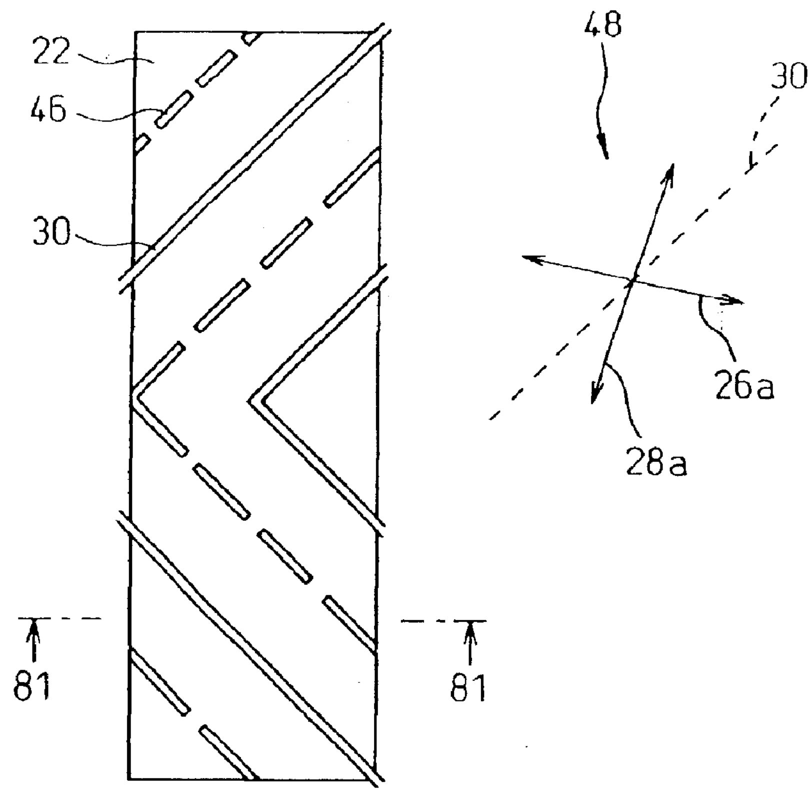

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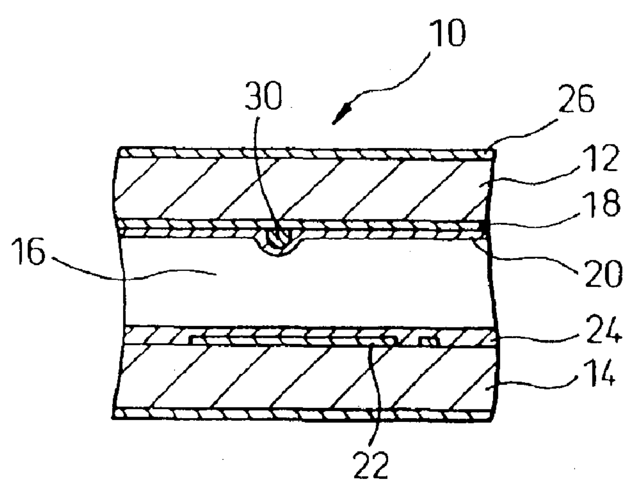

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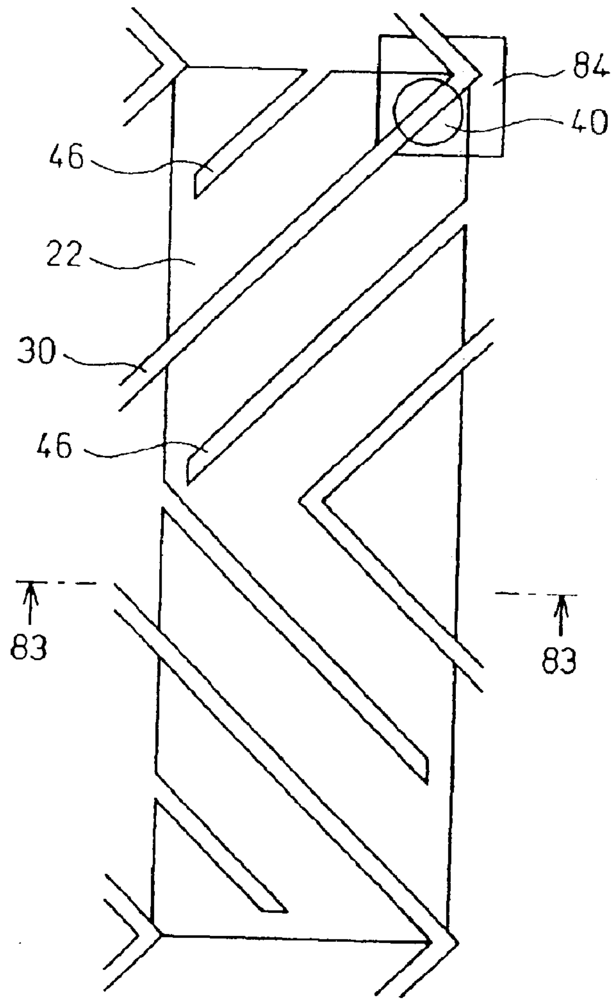

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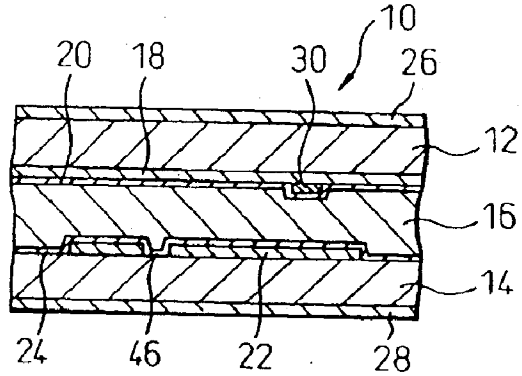

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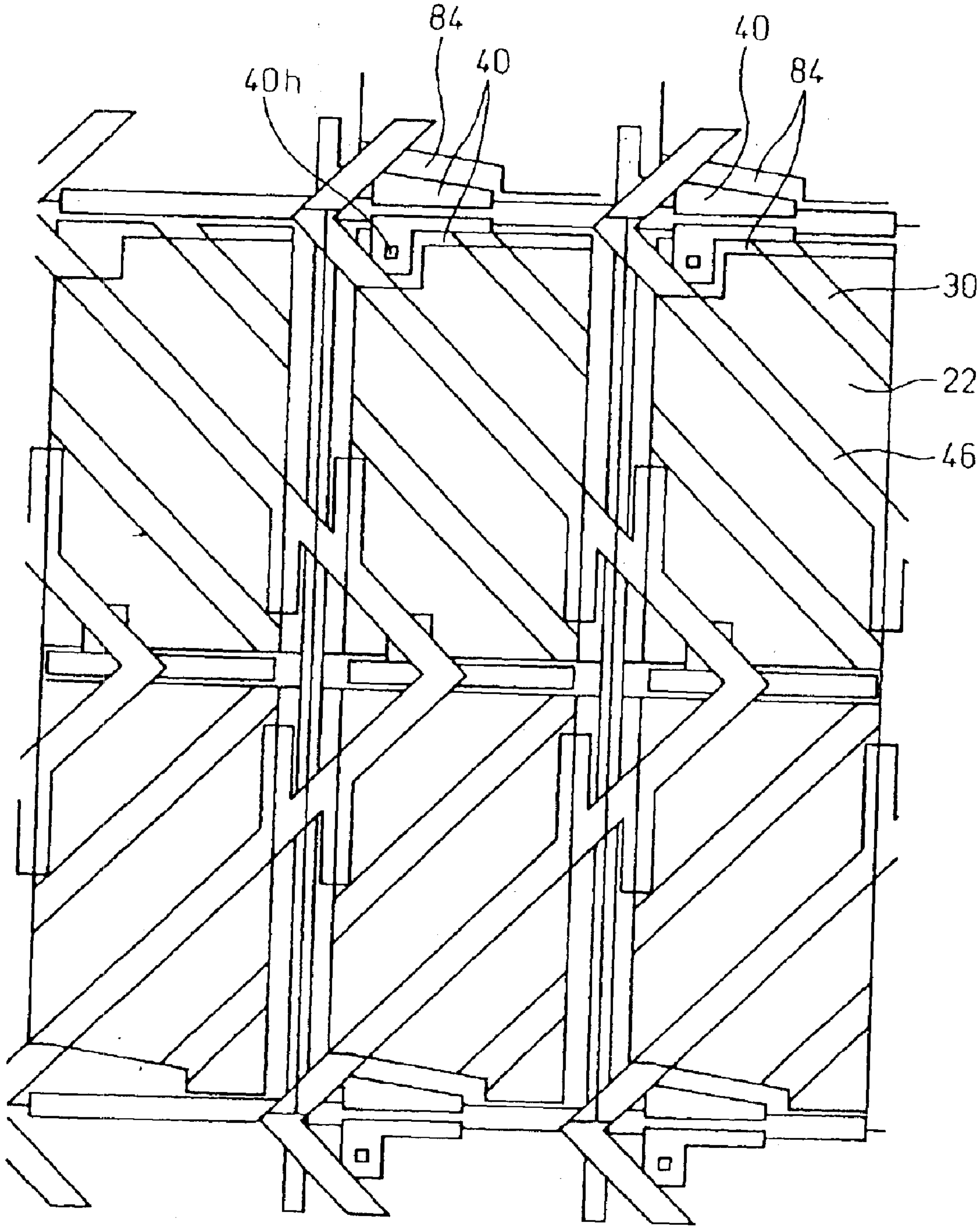
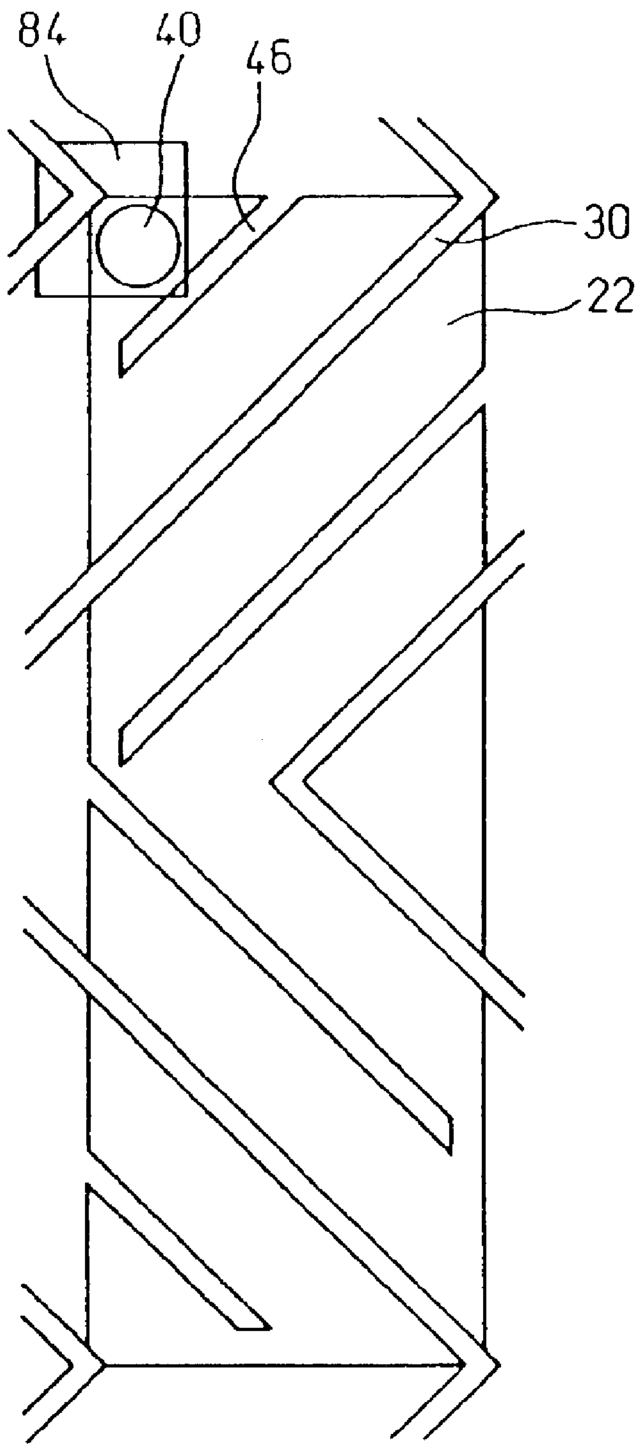


Fig. 85



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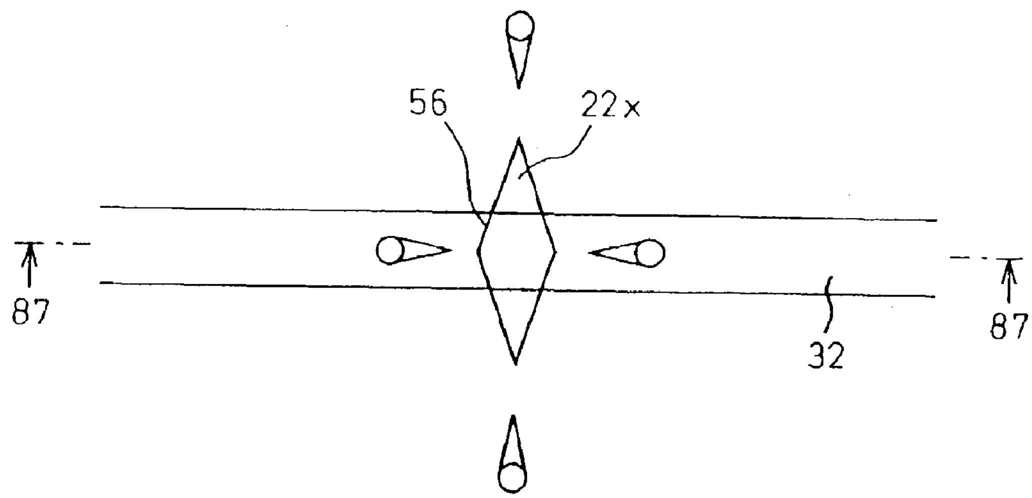
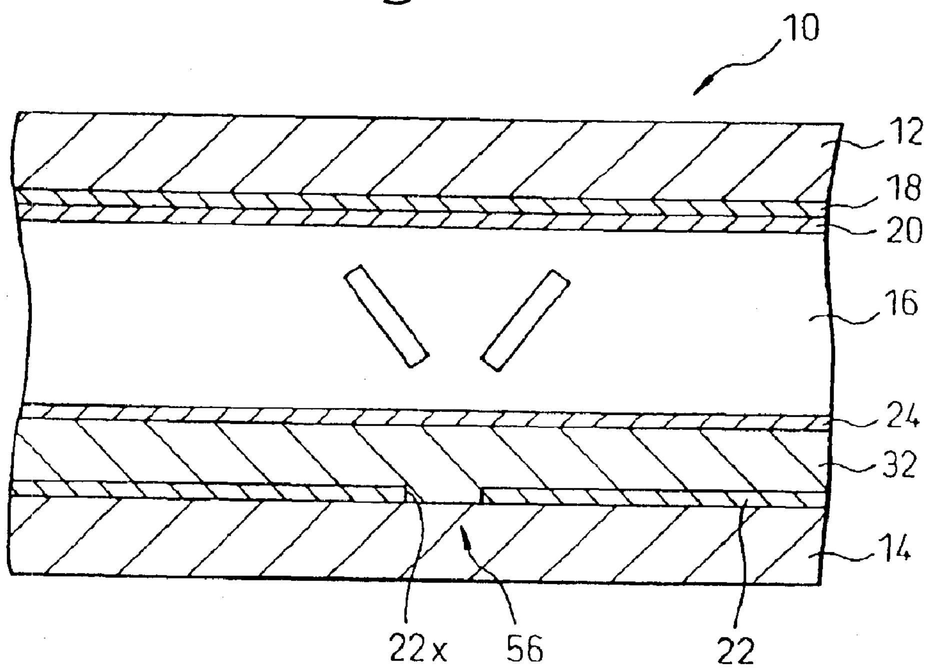


Fig. 87



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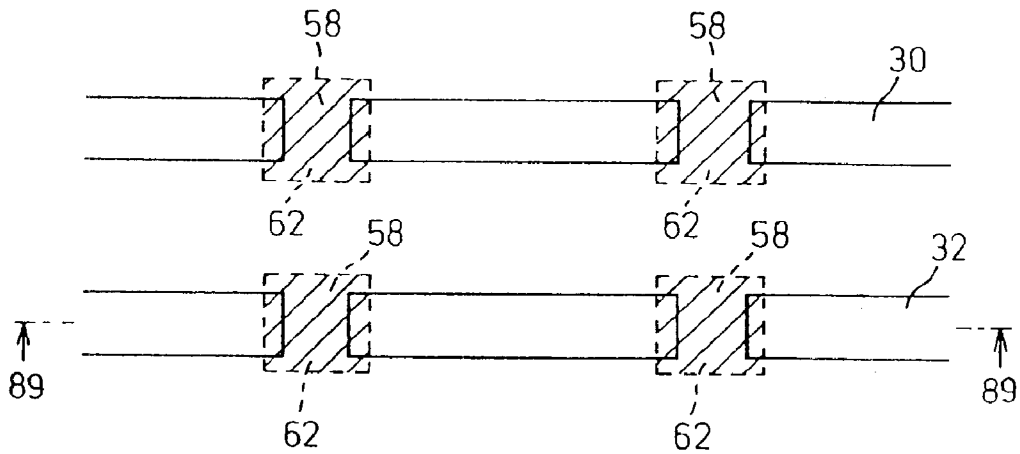
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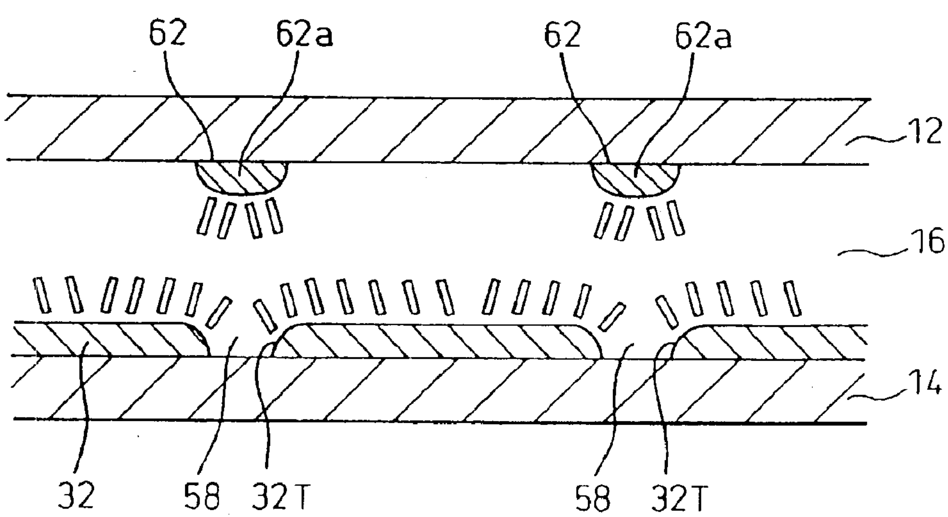
Fig. 89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32T
58
32T

Fig.90

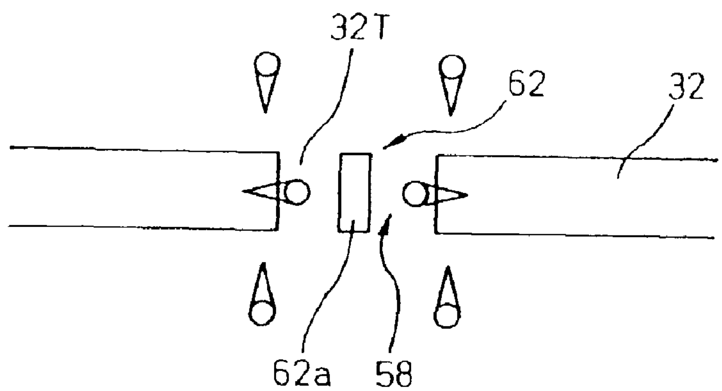
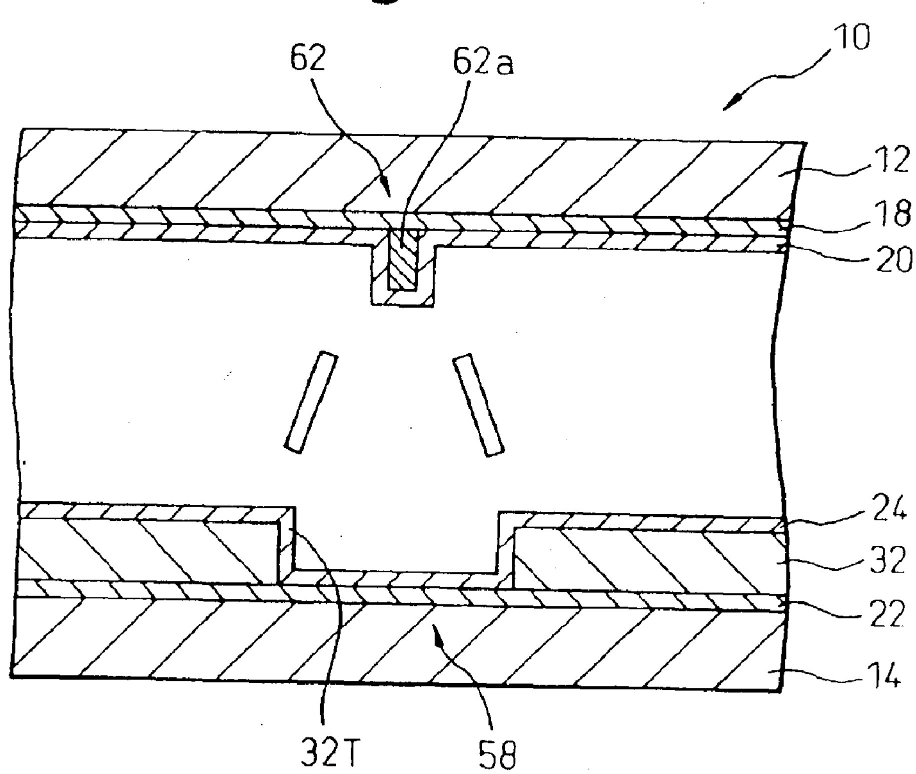


Fig.91



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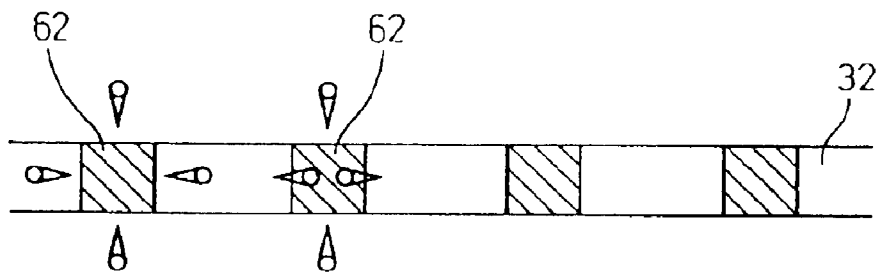

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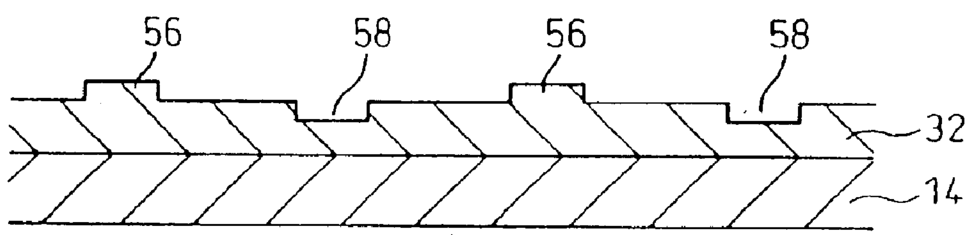

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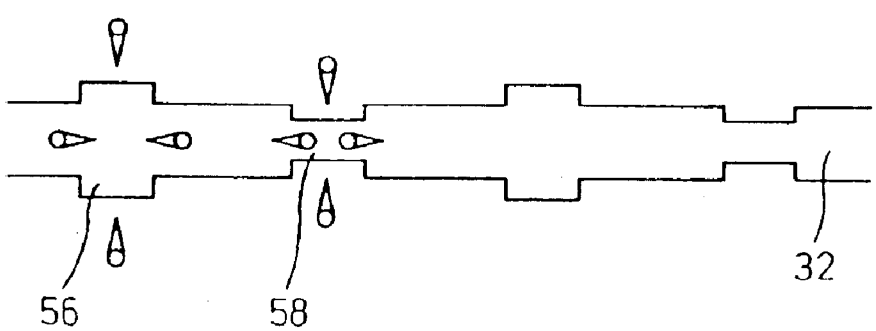

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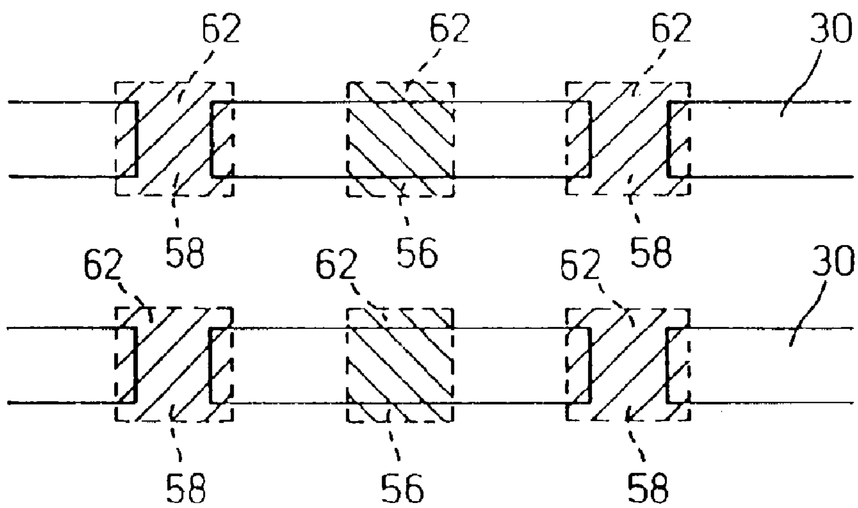

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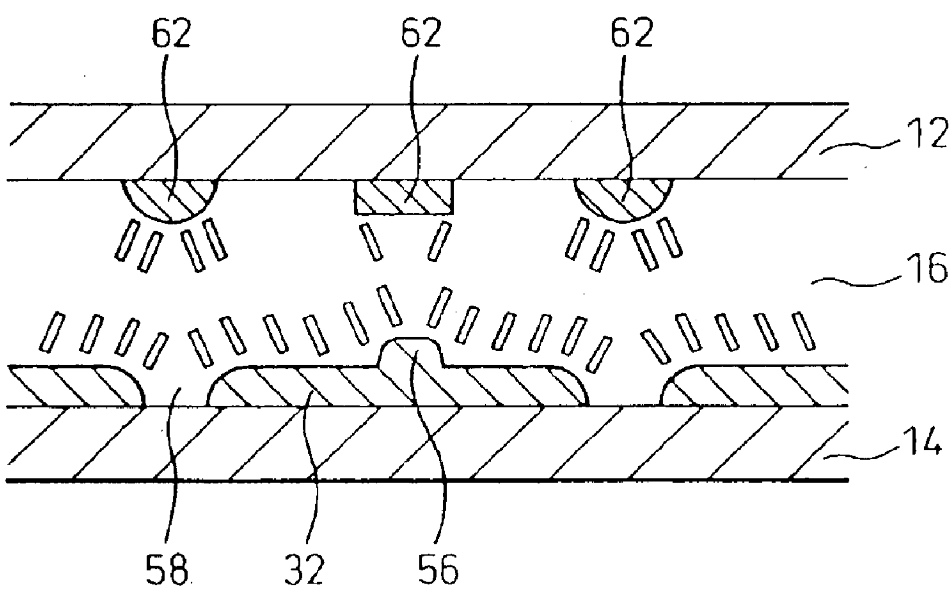

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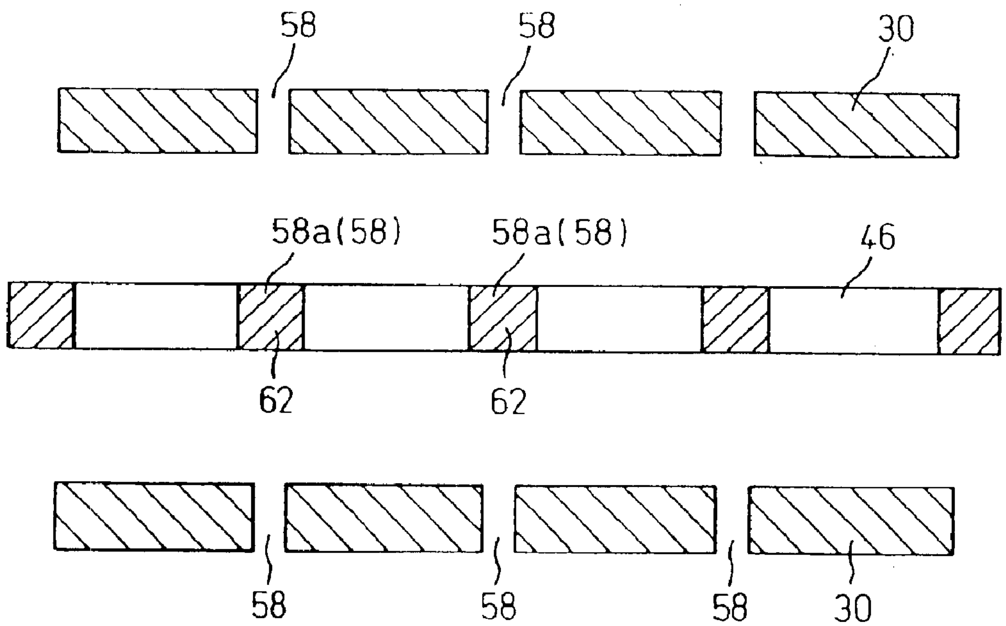
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58a(58)
58a(58)
46
62
62
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58
58
30

Fig. 98

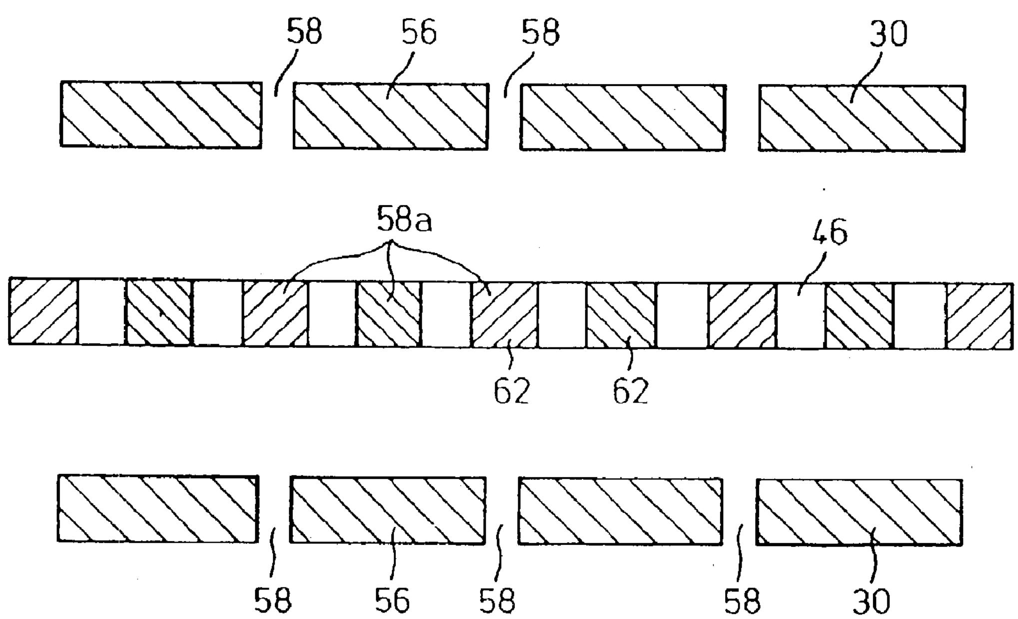
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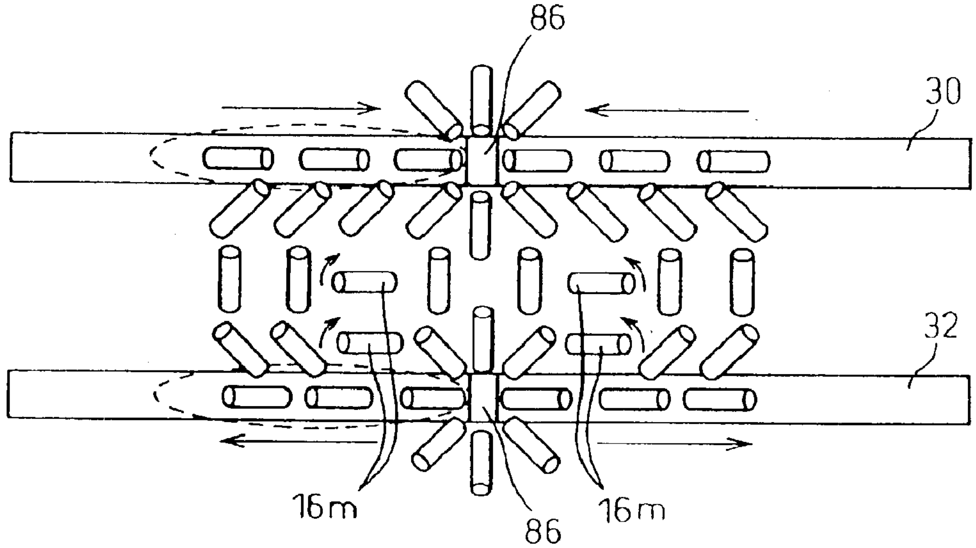
Fig. 99



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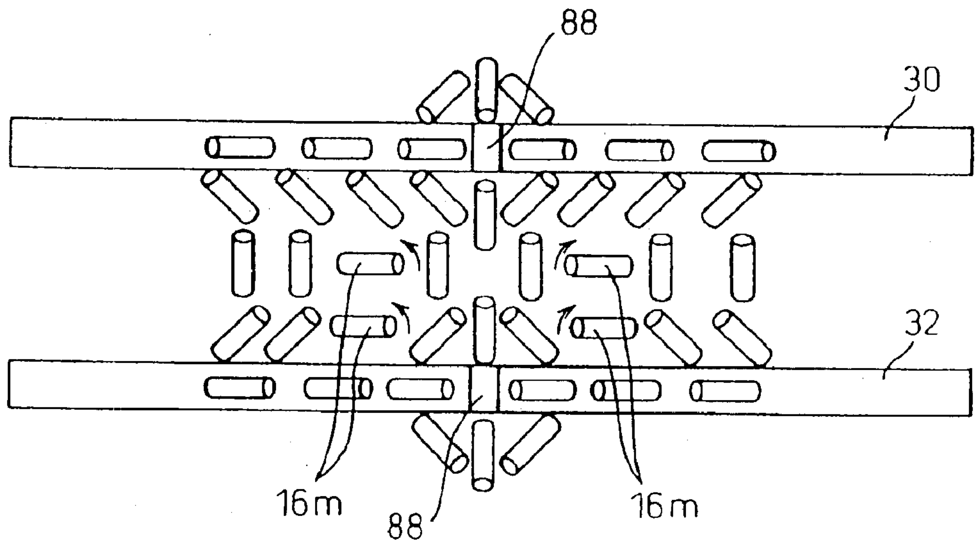

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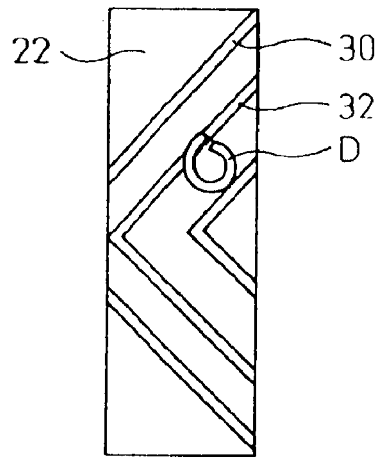

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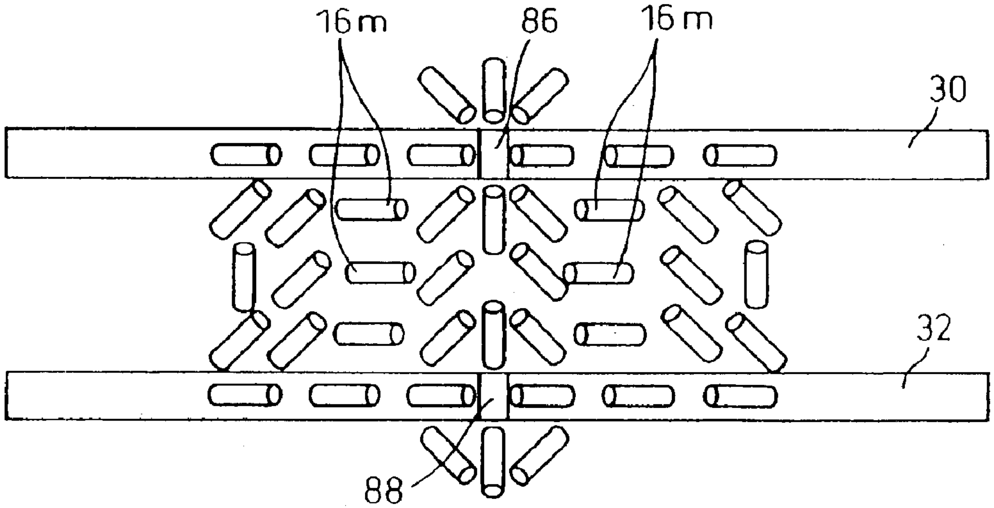

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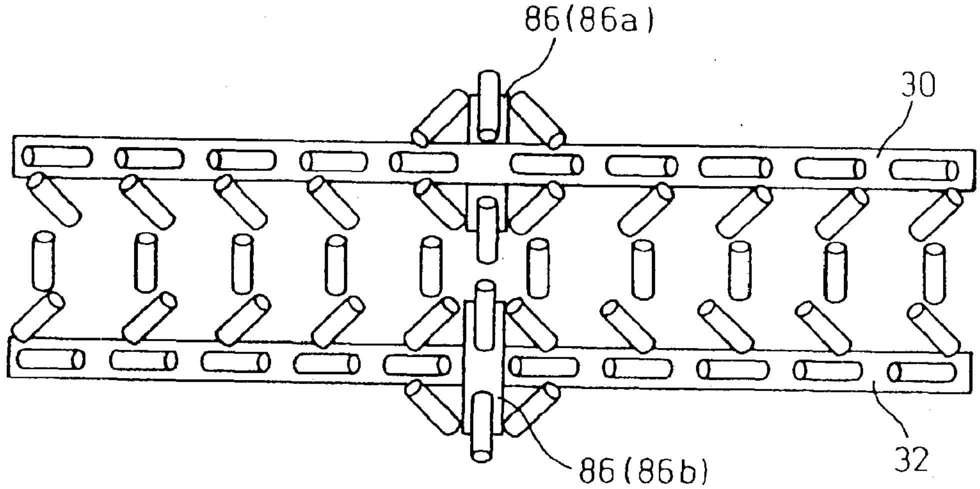

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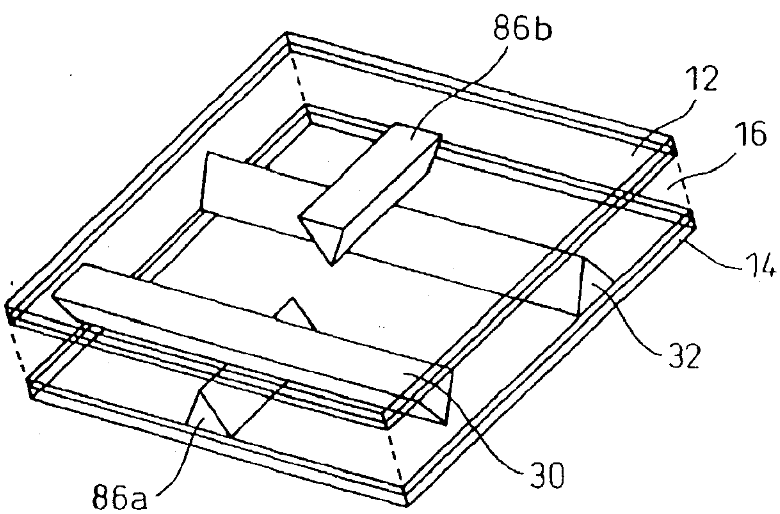

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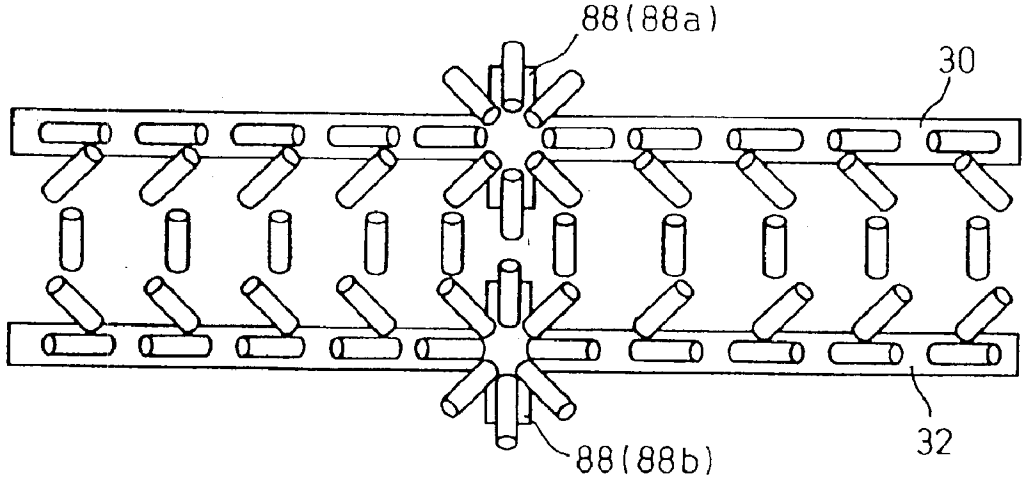


Fig. 106

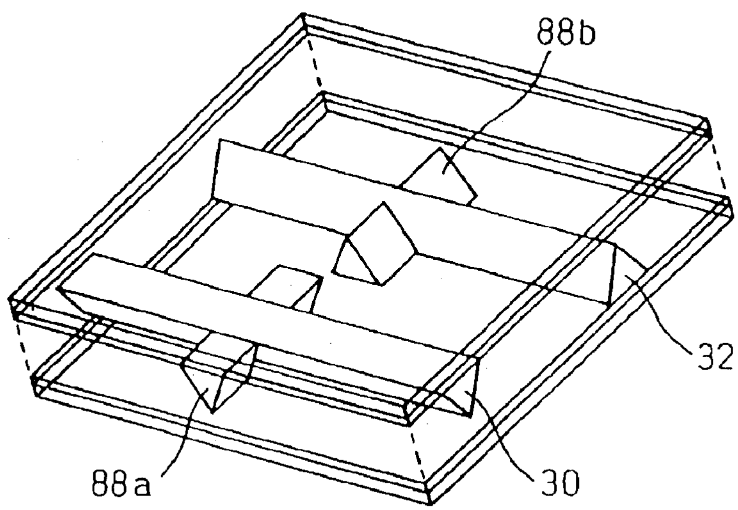


Fig. 107

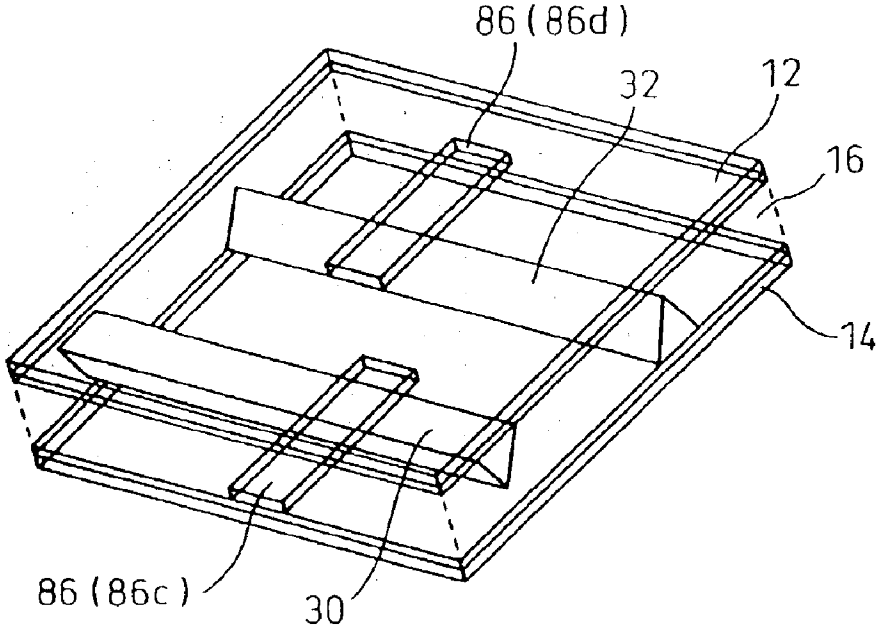
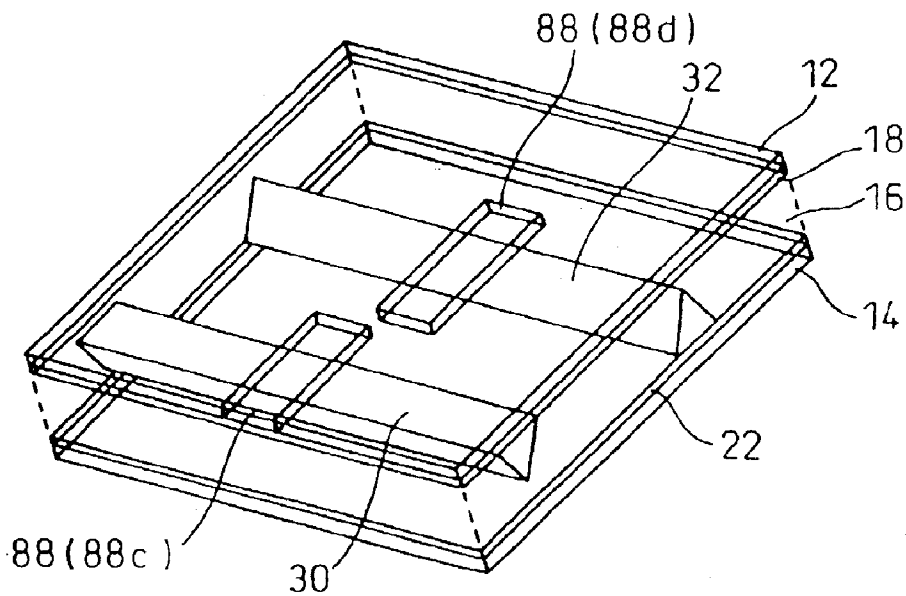


Fig. 108



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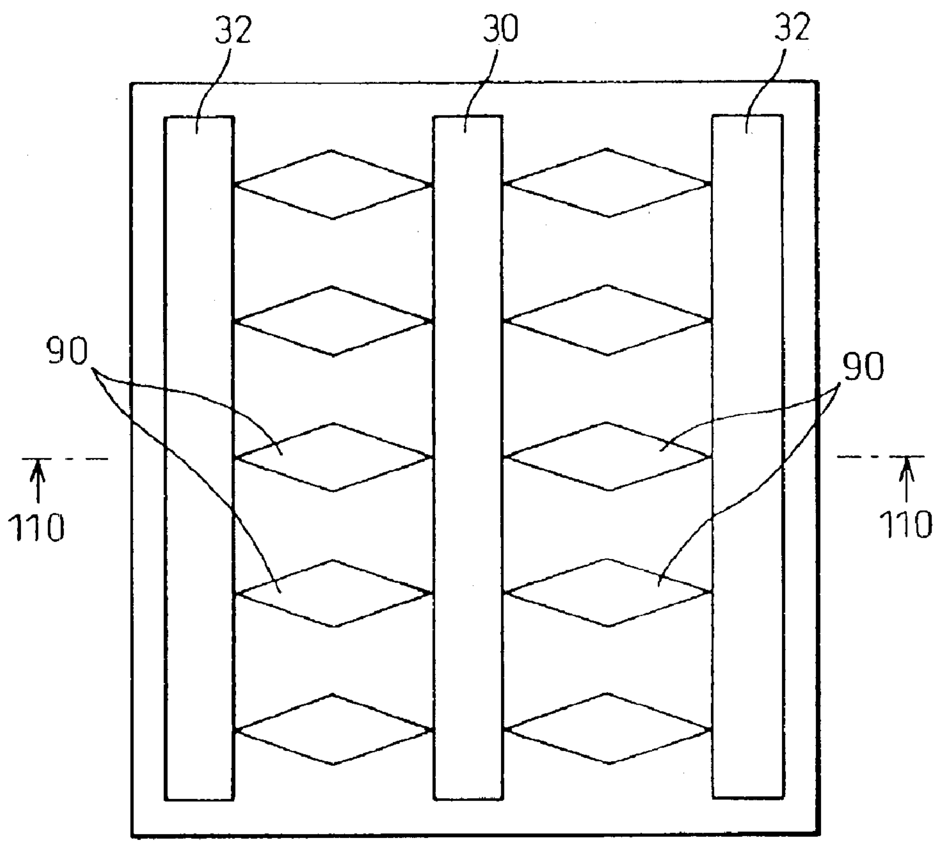


Fig. 110

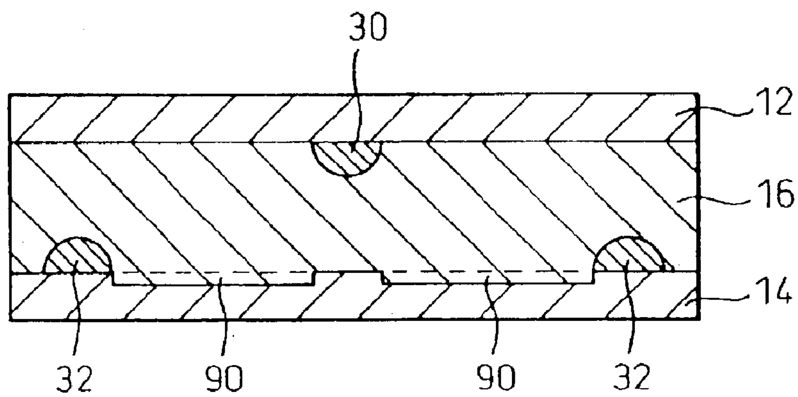


Fig.111

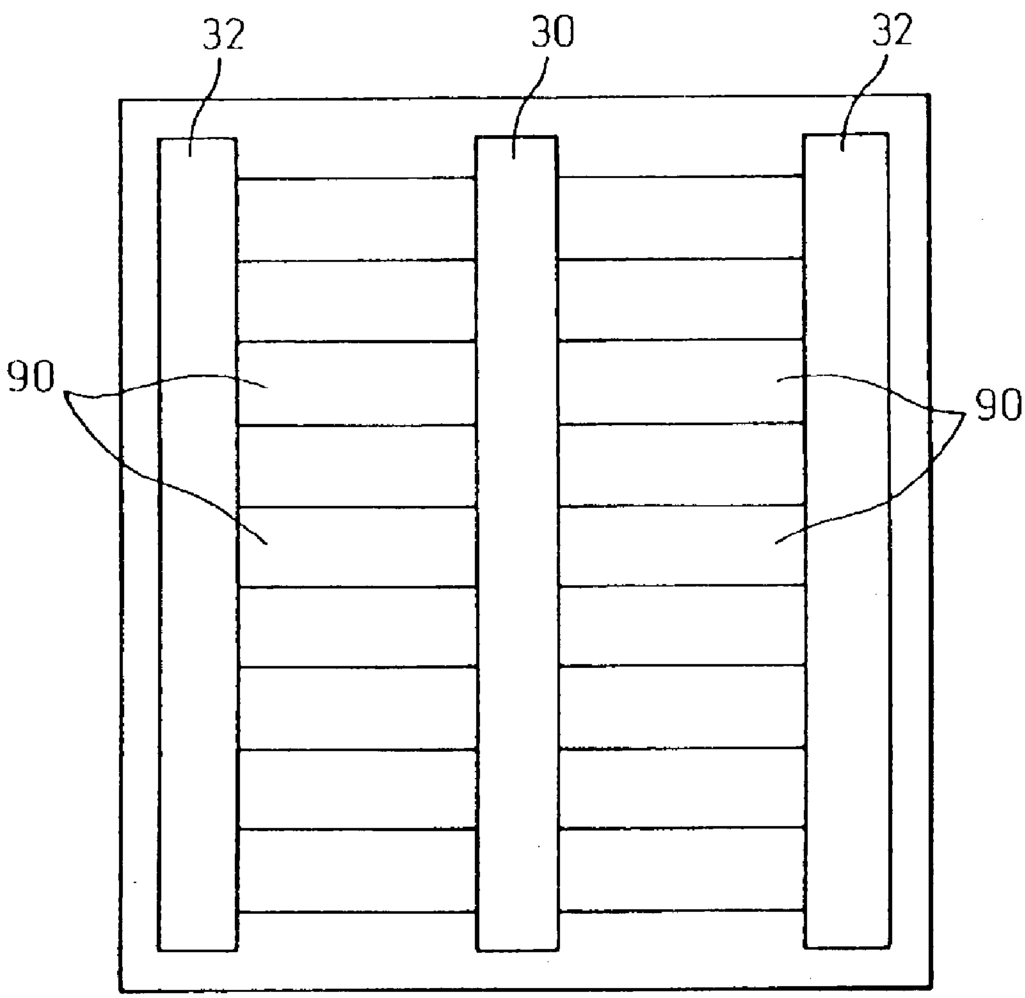


Fig. 112

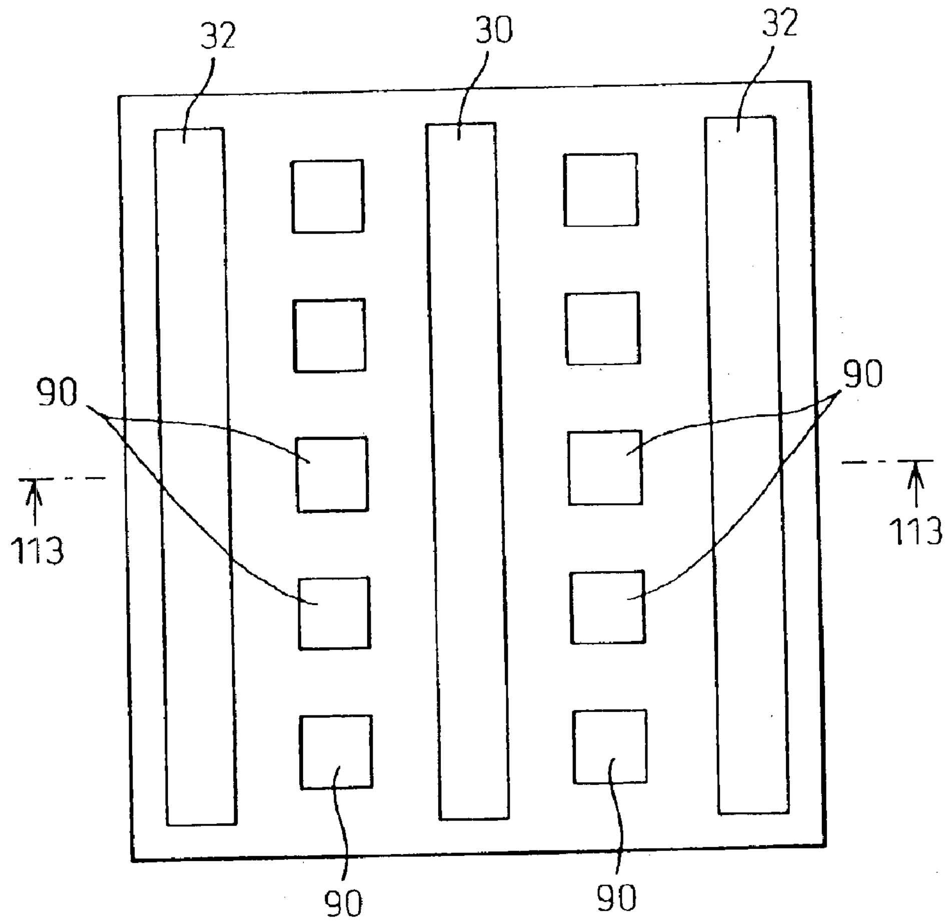
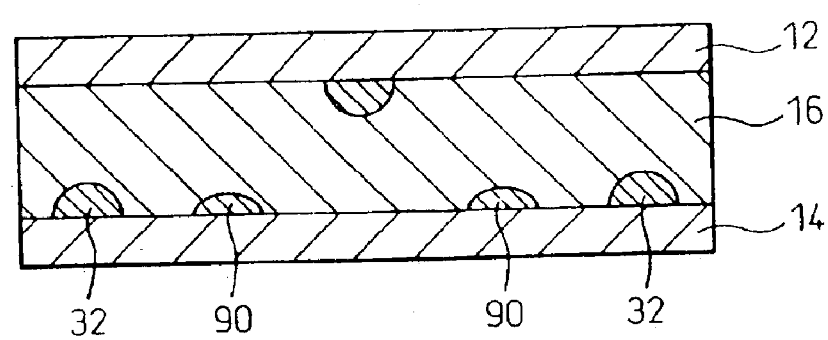


Fig. 113



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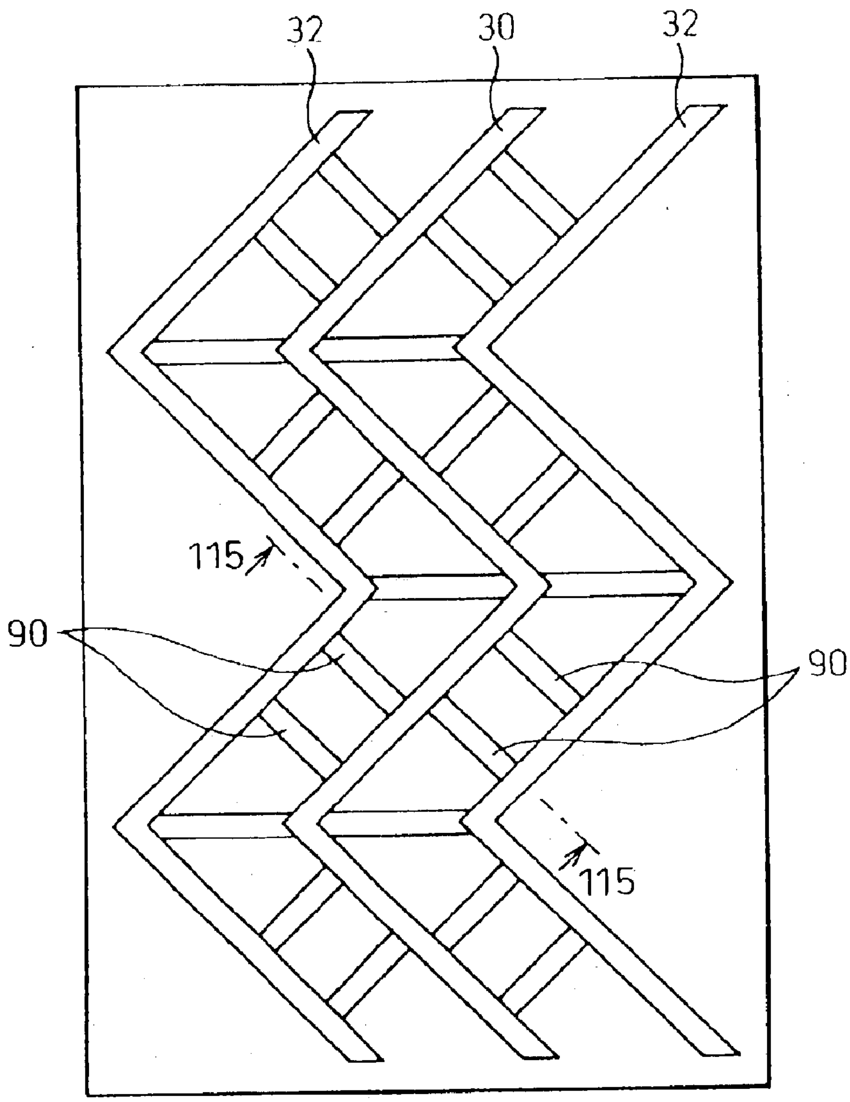


Fig. 115

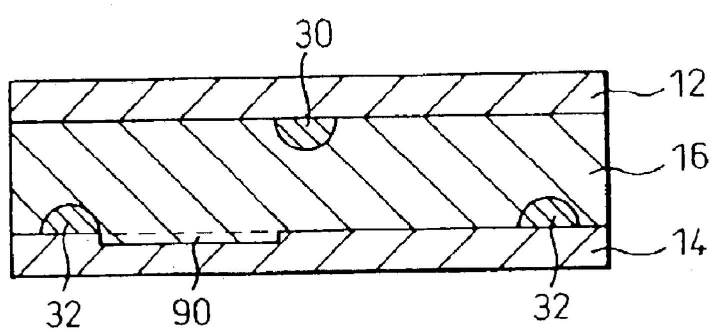


Fig.116A

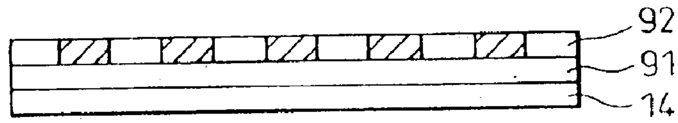


Fig.116B

Fig.116C

Fig.116D

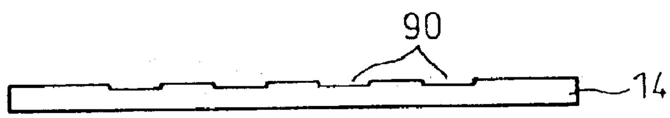


Fig.116E

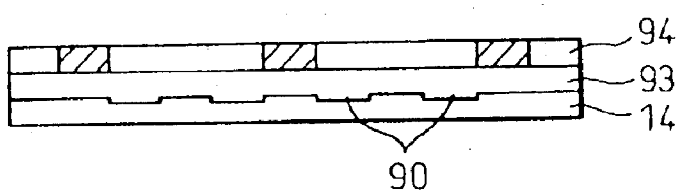


Fig.116F

Fig.116G

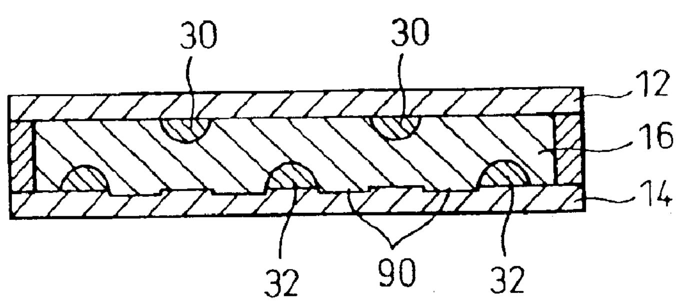


Fig.117A

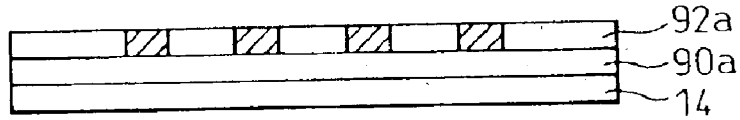


Fig.117B

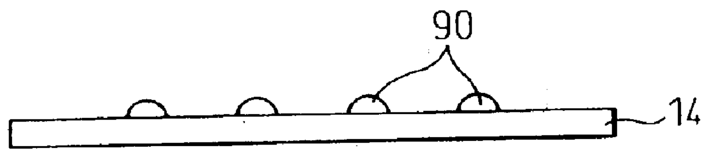


Fig.117C

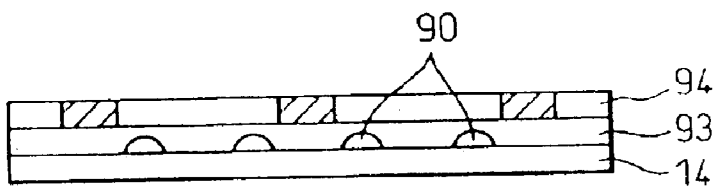


Fig.117D

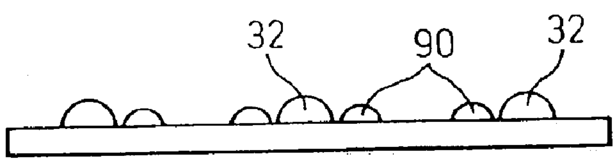


Fig.117E

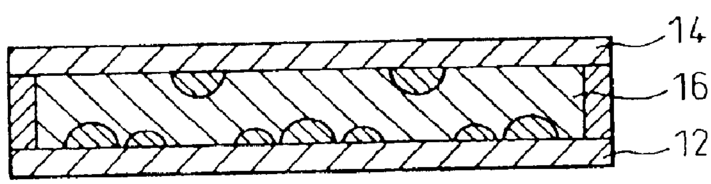
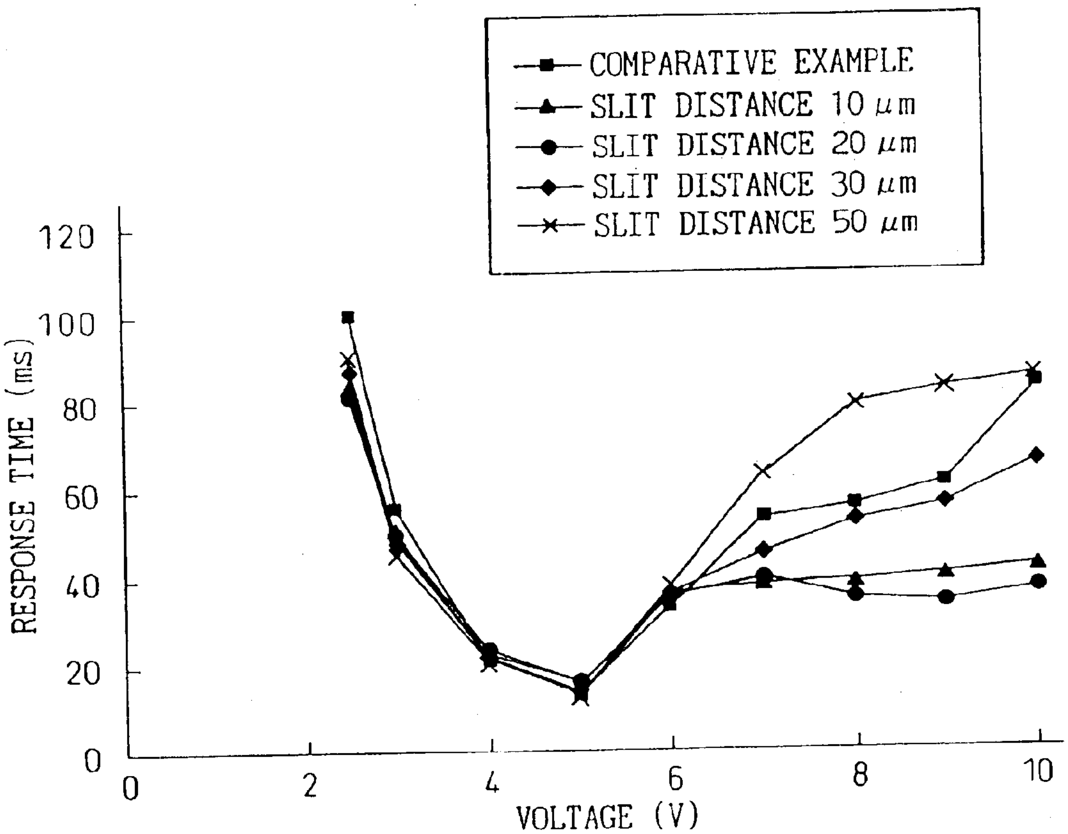
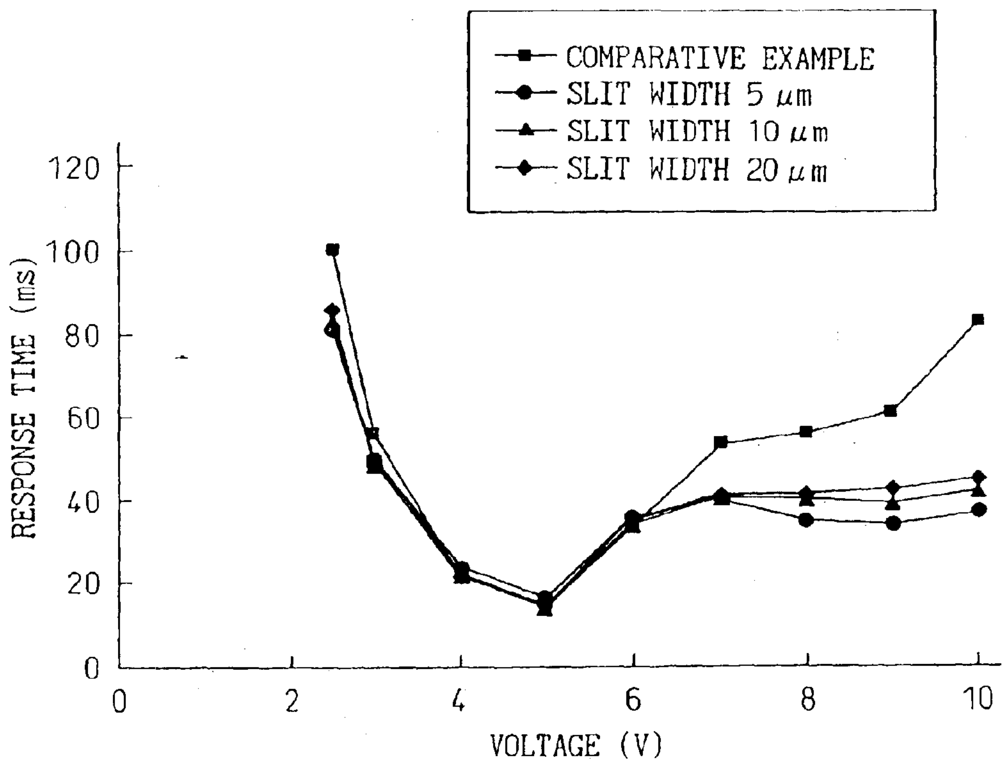


Fig.118



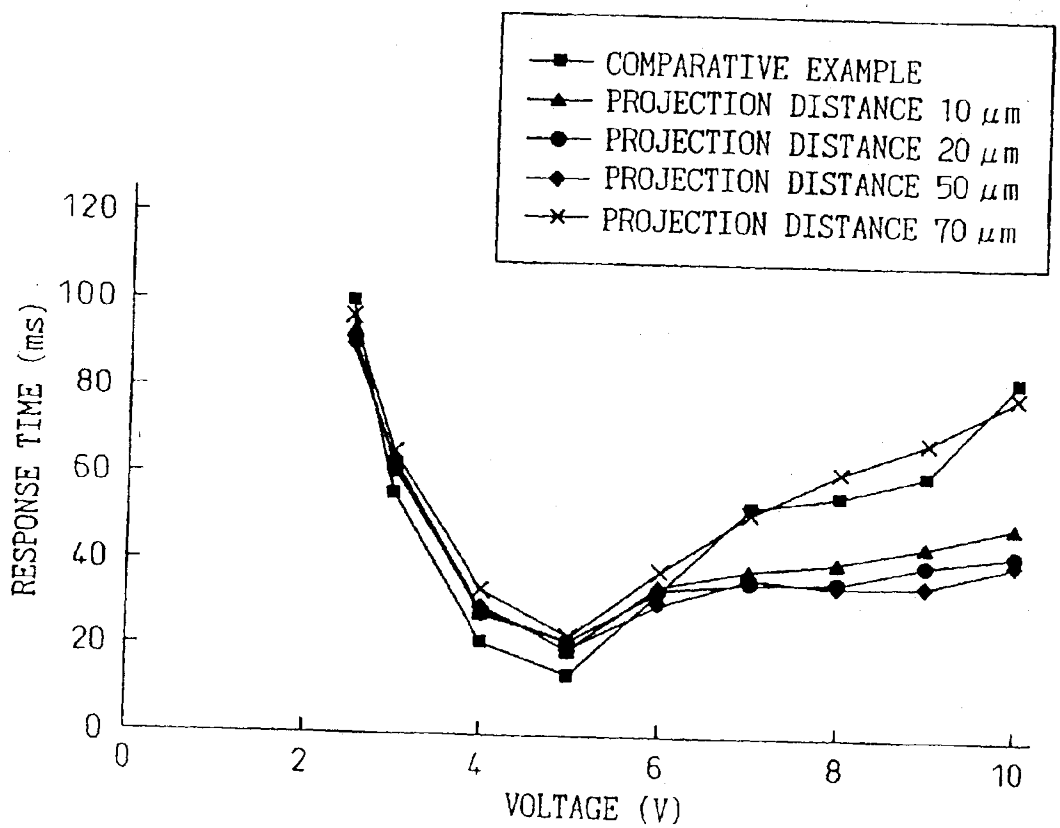
COMPARATIVE EXAMPLE
SLIT DISTANCE 10 μm
SLIT DISTANCE 20 μm
SLIT DISTANCE 30 μm
SLIT DISTANCE 50 μm
RESPONSE TIME (ms)
120
100
80
60
40
20
0
0
2
4
6
8
10
VOLTAGE (V)

Fig.119



COMPARATIVE EXAMPLE
SLIT WIDTH 5 μm
SLIT WIDTH 10 μm
SLIT WIDTH 20 μm
RESPONSE TIME (ms)
120
100
80
60
40
20
0
0
2
4
6
8
10
VOLTAGE (V)

Fig.120


COMPARATIVE EXAMPLE
PROJECTION DISTANCE 10 μm
PROJECTION DISTANCE 20 μm
PROJECTION DISTANCE 50 μm
PROJECTION DISTANCE 70 μm
RESPONSE TIME (ms)
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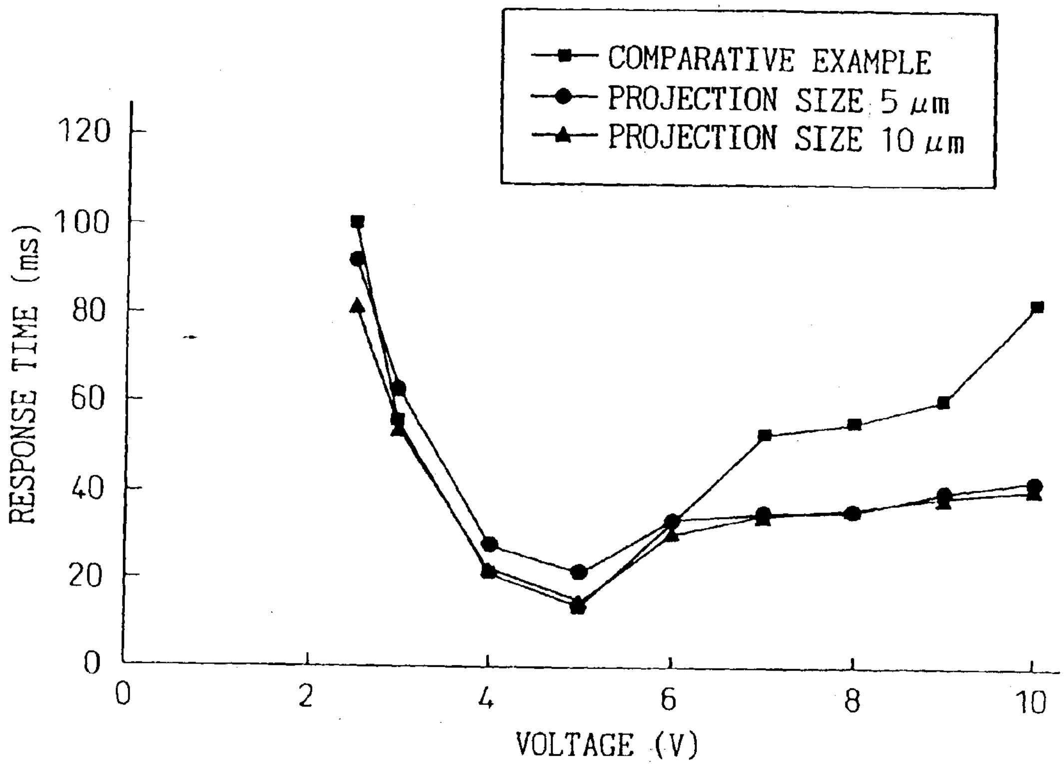
20
40
60
80
100
120
0
2
4
6
8
10
VOLTAGE (V)

Fig.121



COMPARATIVE EXAMPLE
PROJECTION SIZE 5 μm
PROJECTION SIZE 10 μm
RESPONSE TIME (ms)
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100
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60
40
20
0
0
2
4
6
8
10
VOLTAGE (V)

Fig.122

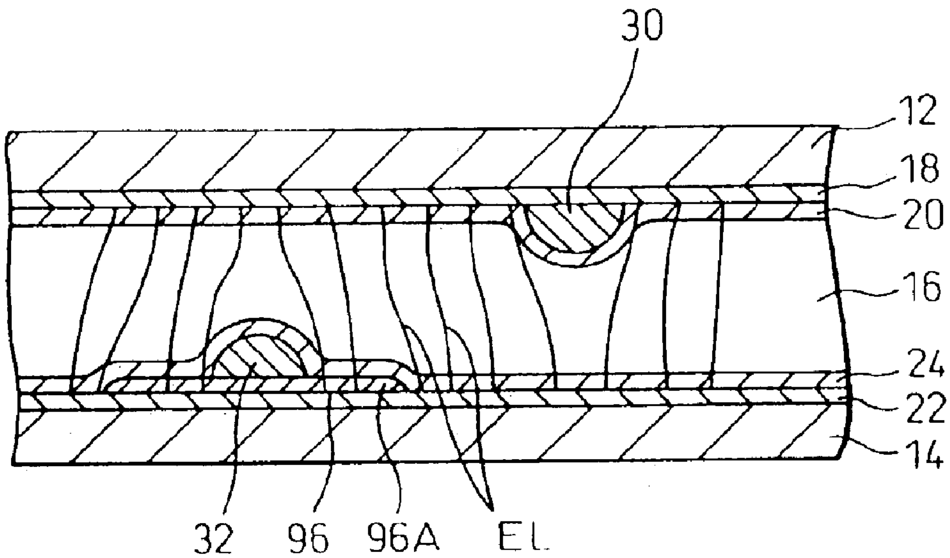


Fig.123

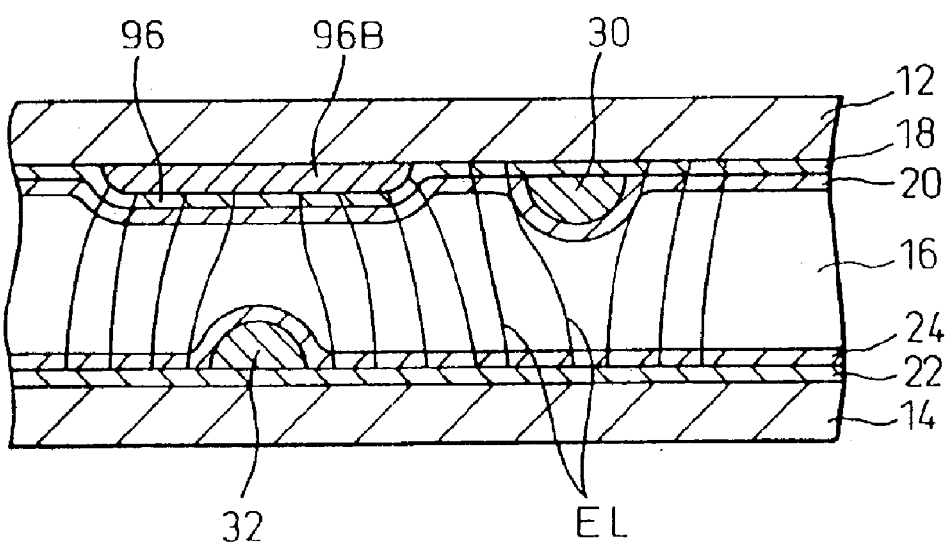


Fig. 124A

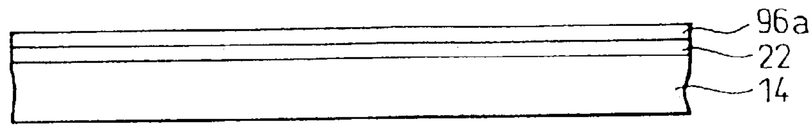


Fig. 124B

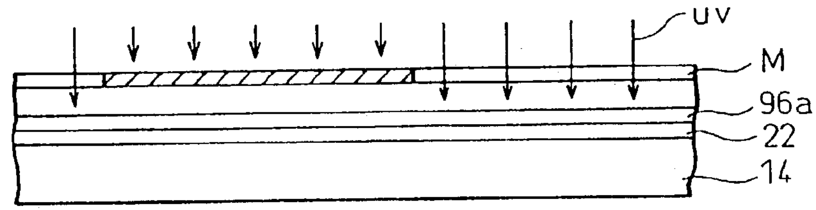


Fig. 124C

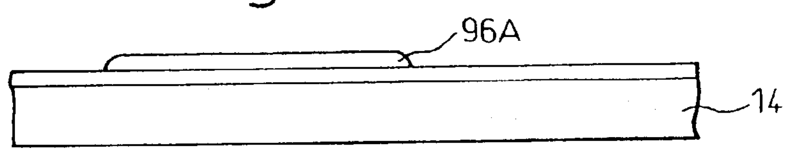


Fig. 124D

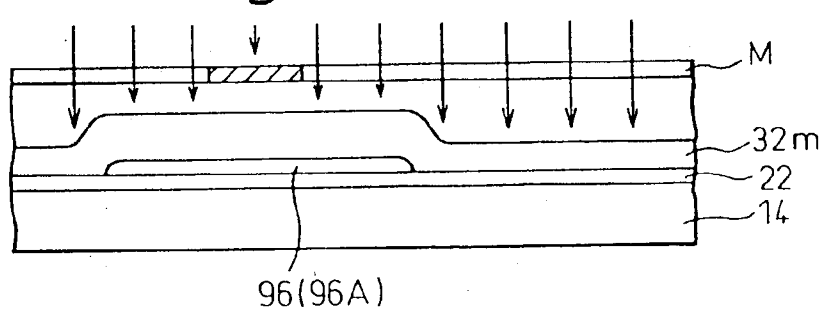


Fig. 124E

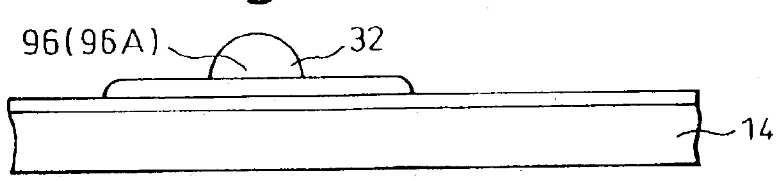


Fig.125A

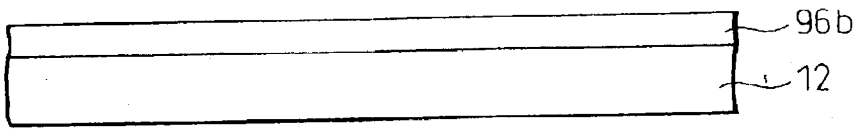


Fig.125B

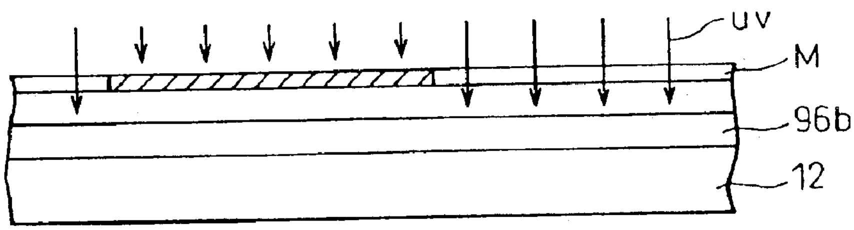


Fig.125C

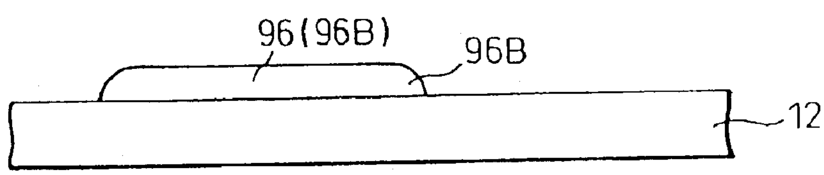


Fig.125D

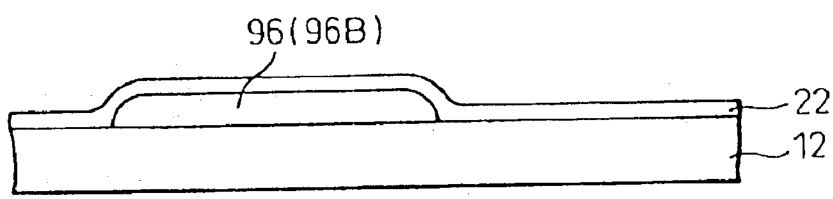


Fig.125E

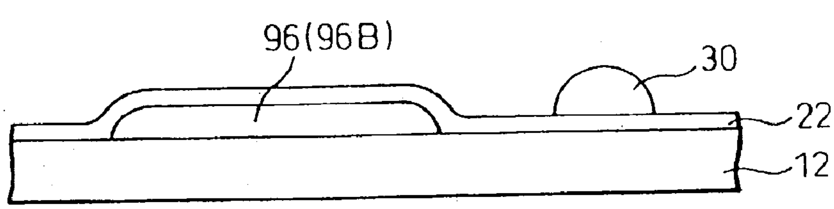


Fig.126

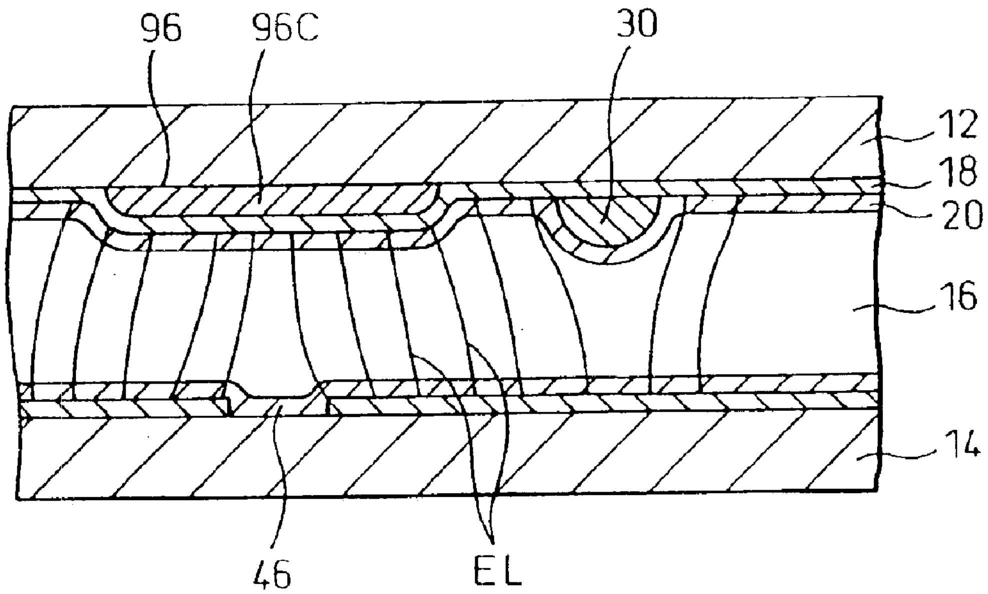


Fig.127

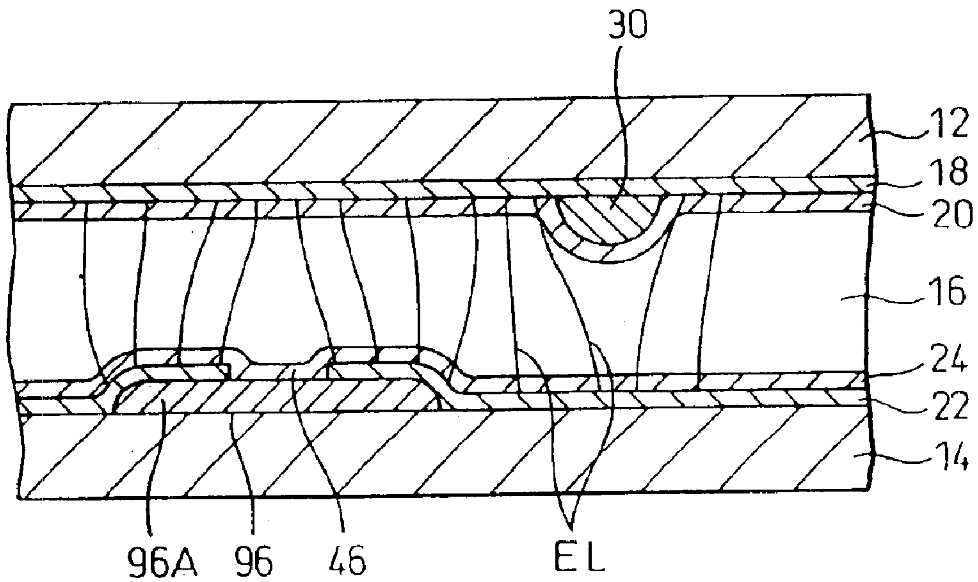


Fig.128

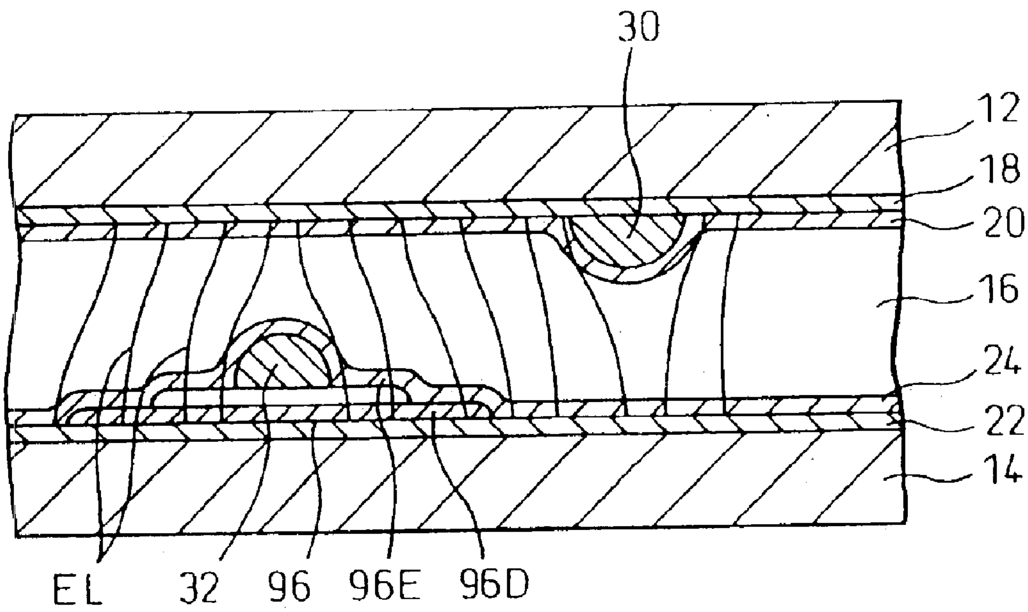


Fig.129

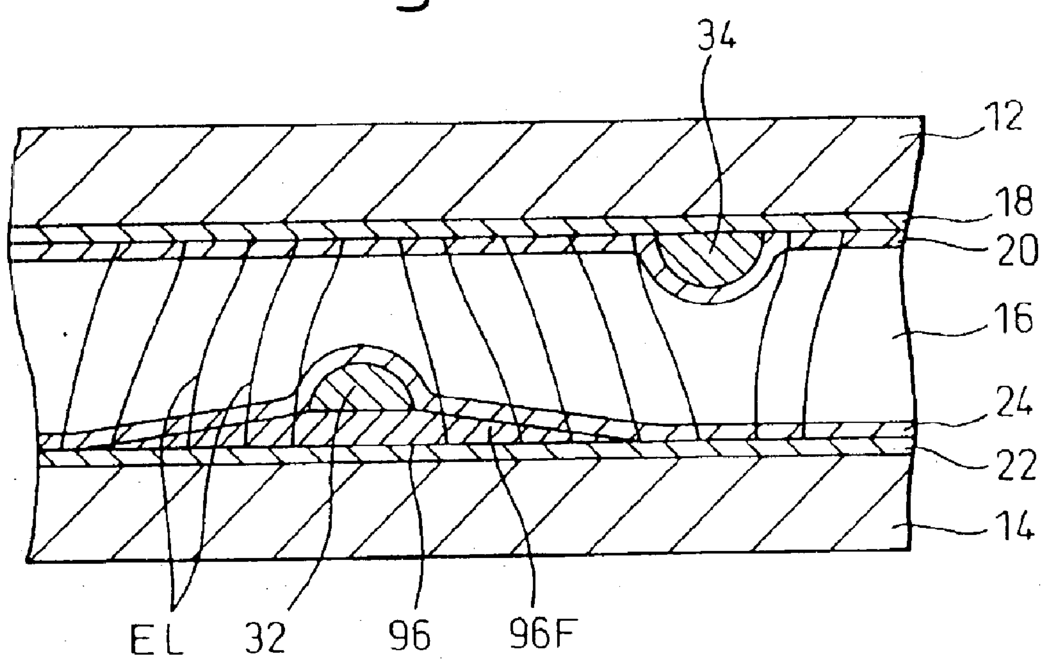


Fig. 130

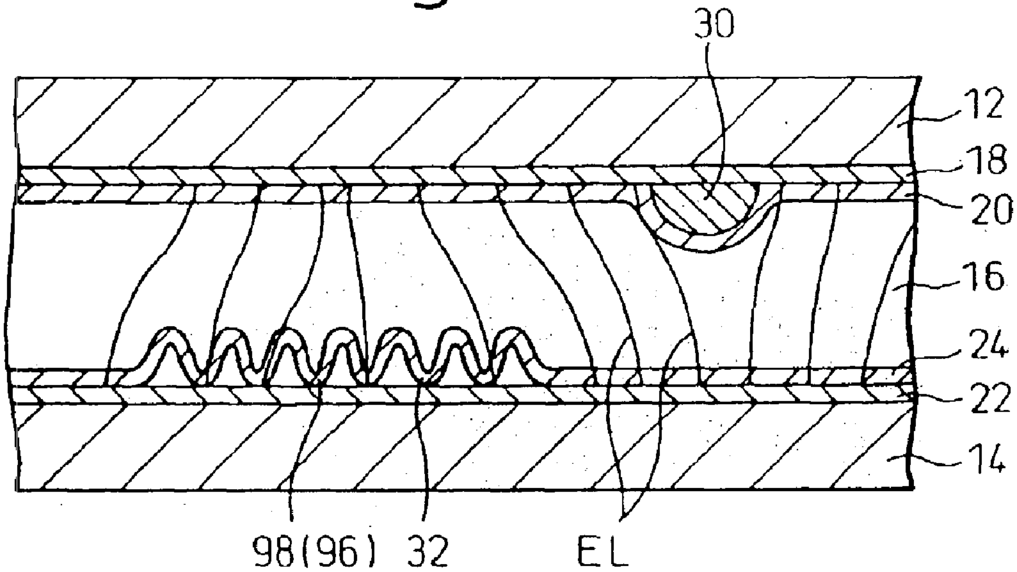


Fig. 131

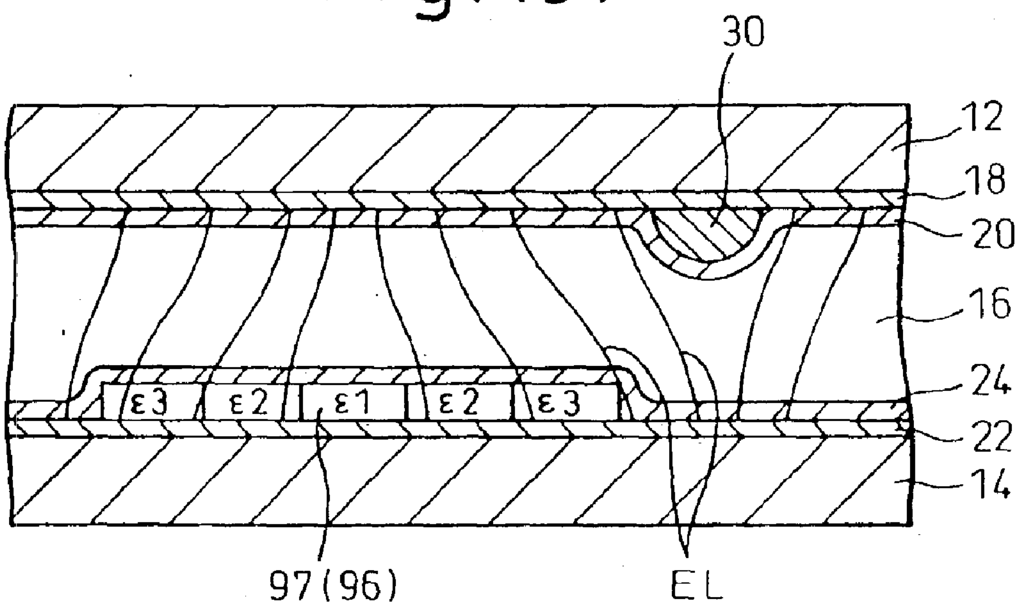


Fig.132

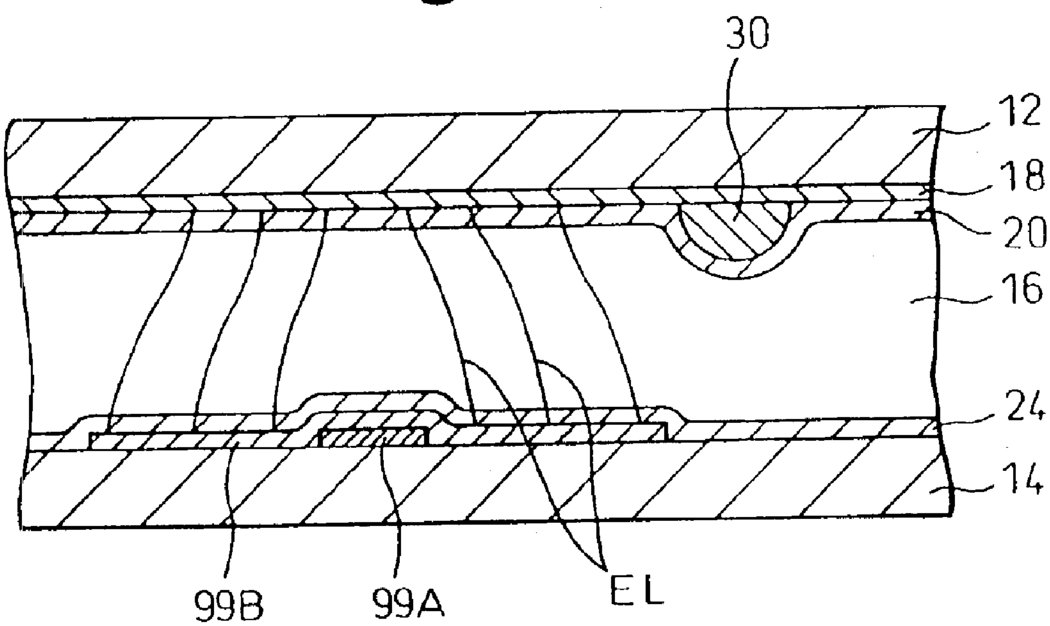


Fig.133A

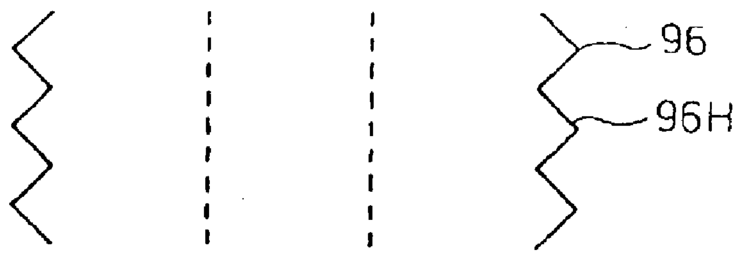


Fig.133B

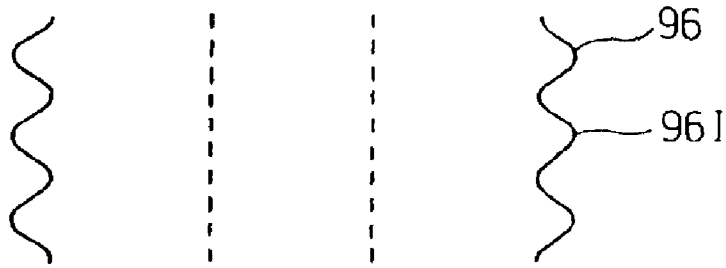


Fig.133C

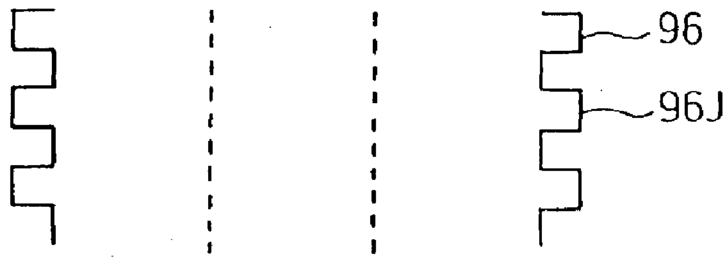


Fig. 134A

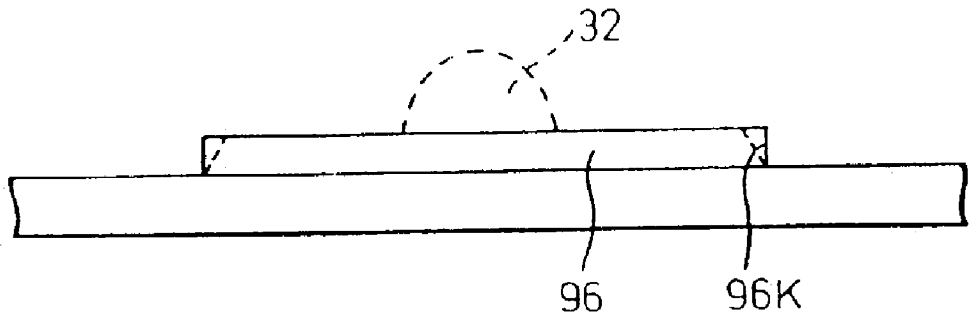


Fig. 134B

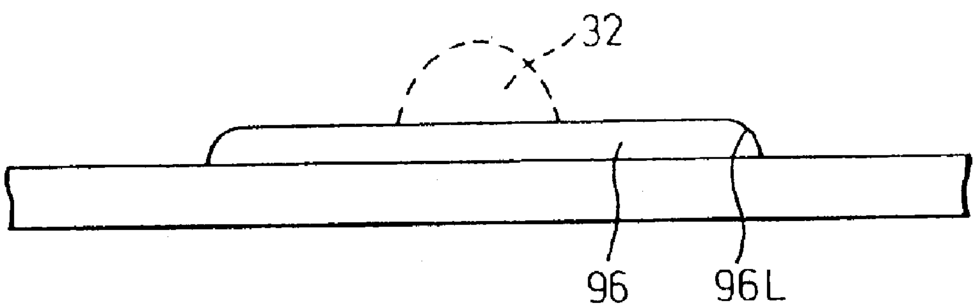


Fig. 134C

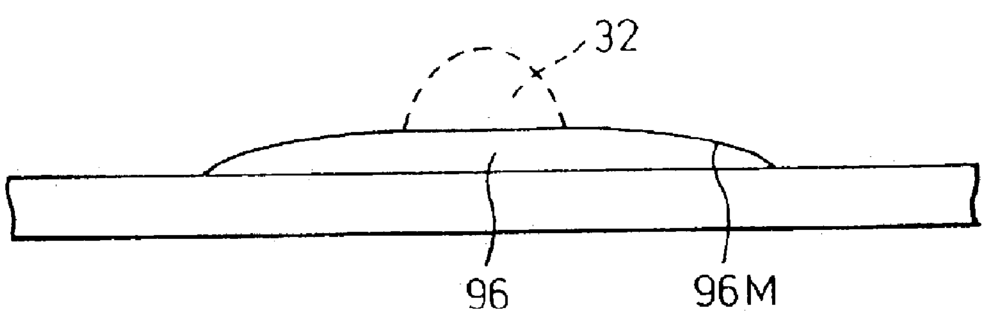


Fig.135A

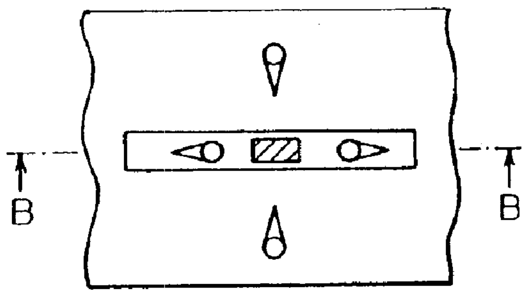


Fig.135B

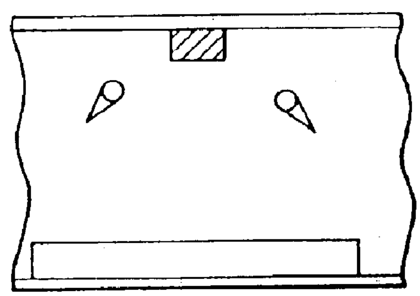


Fig.136A

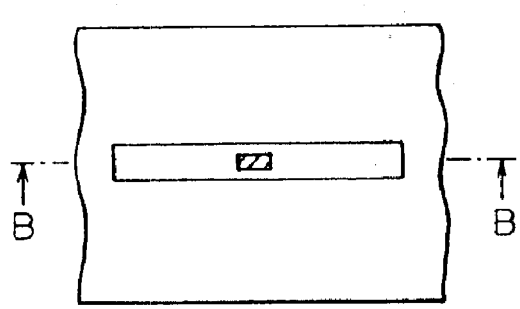


Fig.136B

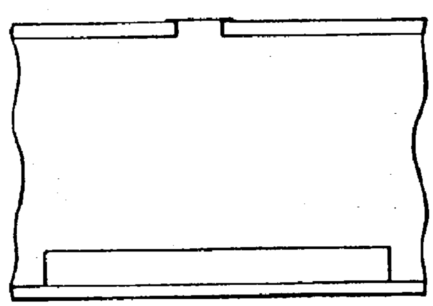


Fig.137A

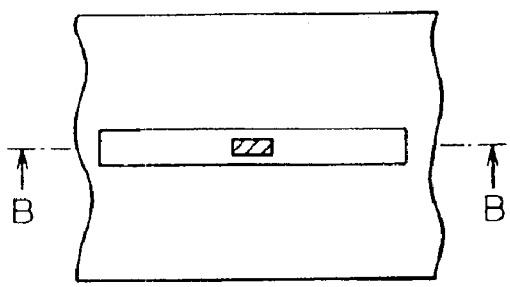


Fig.137B

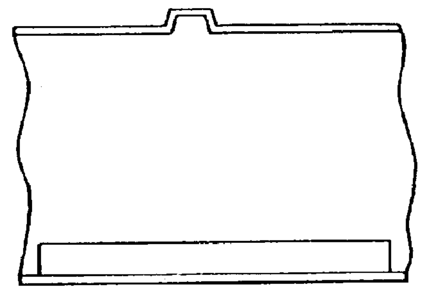


Fig.138A

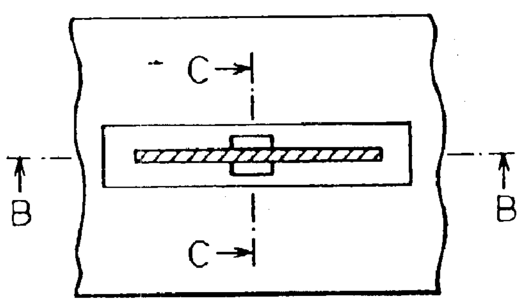


Fig.138B

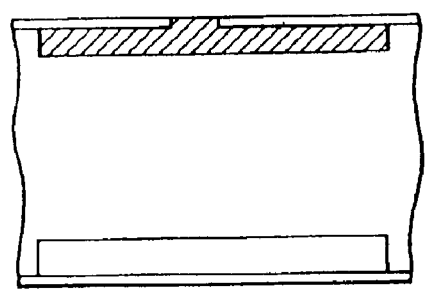


Fig.138C

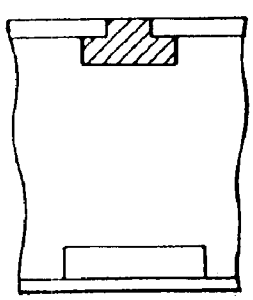


Fig.138D

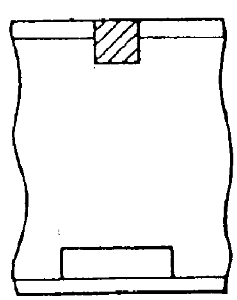


Fig.138E

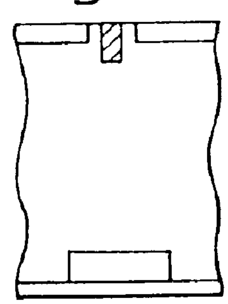


Fig.139A

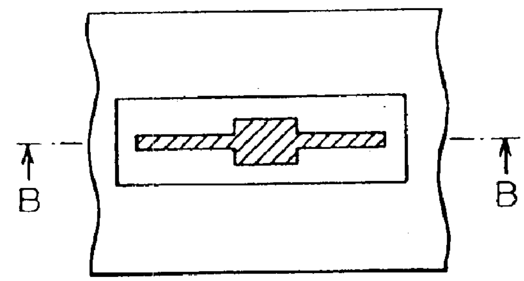


Fig.139B

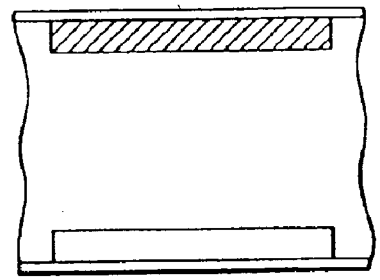


Fig.140A

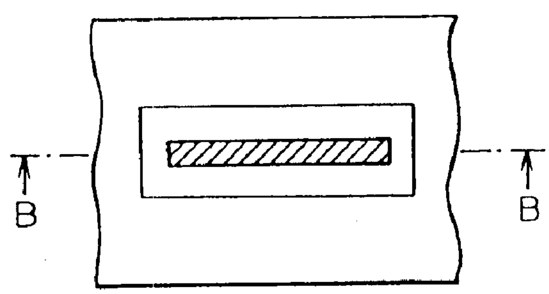


Fig.140B

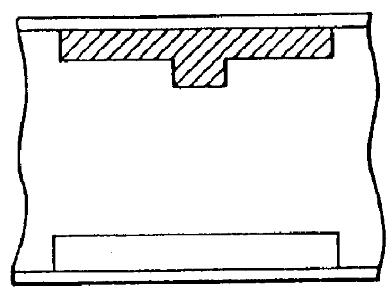


Fig.141A

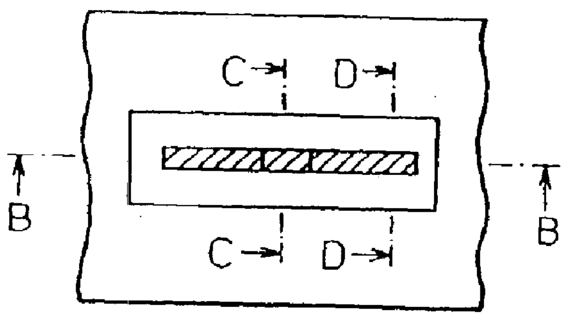


Fig.141B

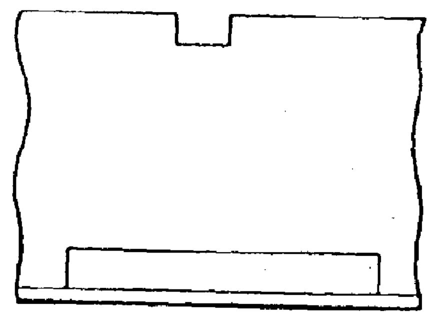


Fig.141C

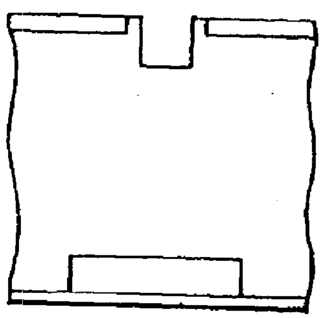


Fig.141D

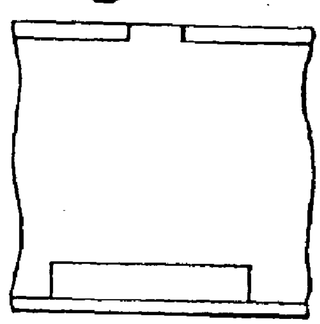


Fig.142A

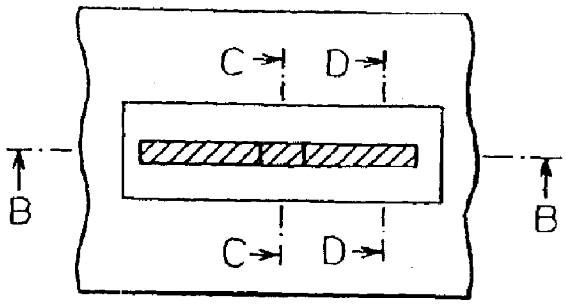


Fig.142B

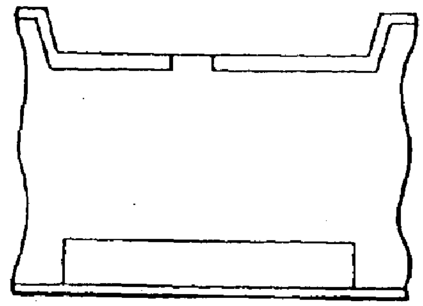


Fig.142C

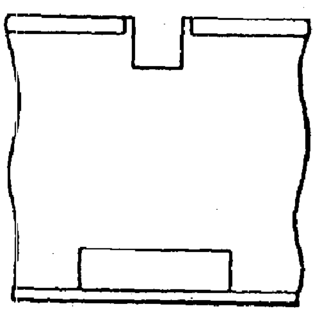


Fig.142D

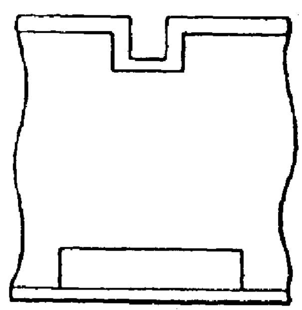


Fig.143A

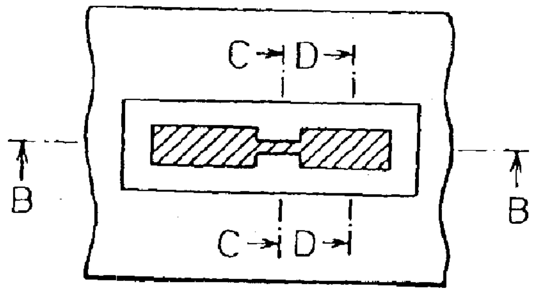


Fig.143B

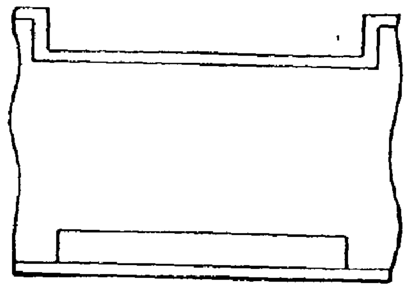


Fig.143C

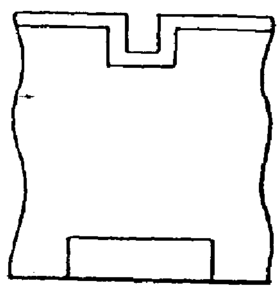


Fig.143D

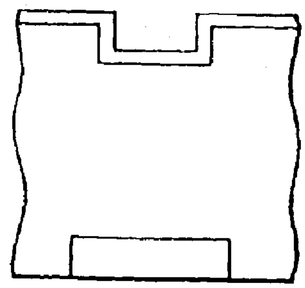


Fig.144A

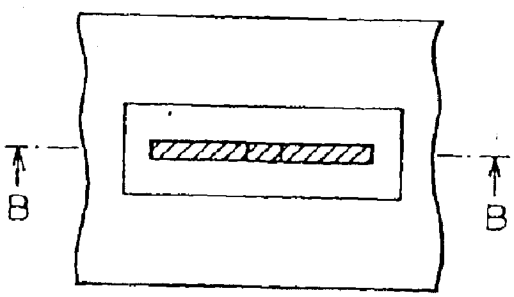


Fig.144B

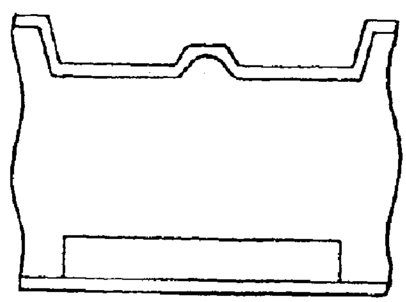


Fig.145A

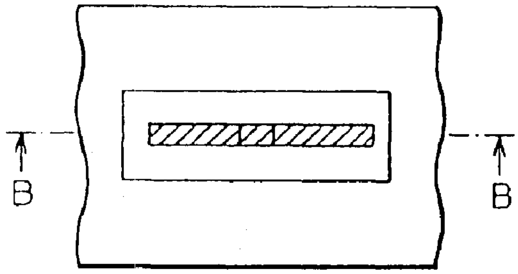


Fig.145B

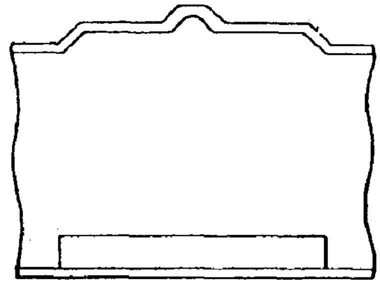


Fig.146A

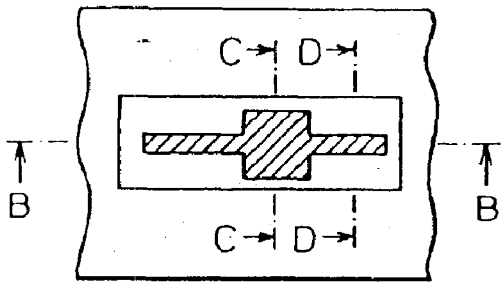


Fig.146B

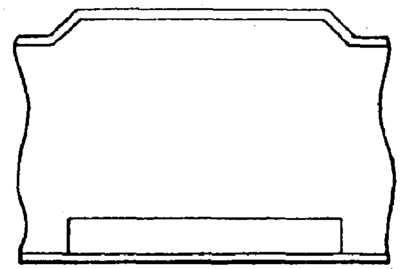


Fig.146C

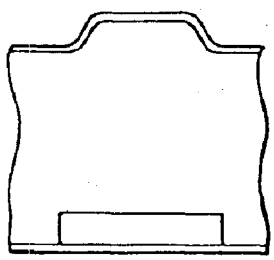


Fig.146D

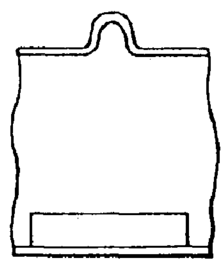


Fig.147A

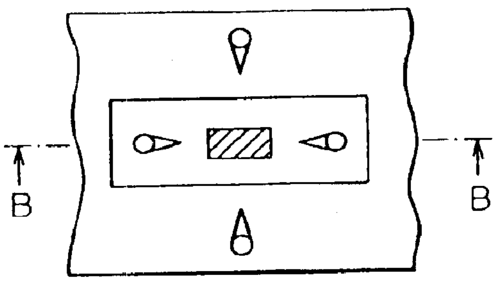


Fig.147B

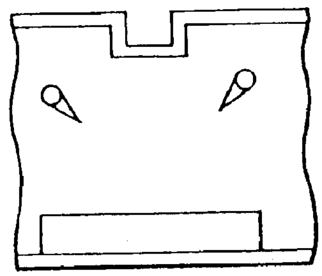


Fig.148A

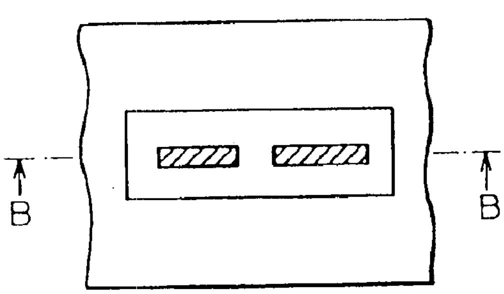


Fig.148B

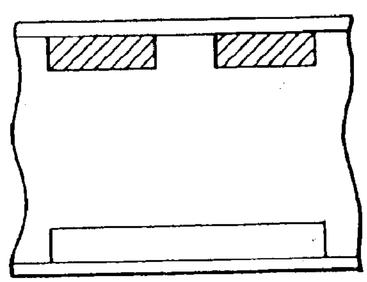


Fig.149A

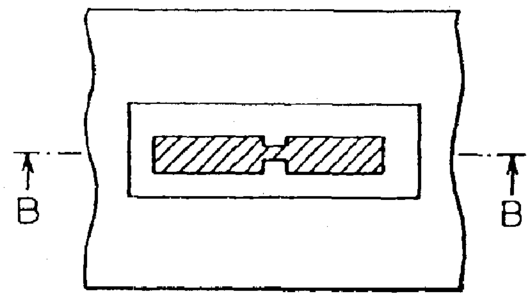


Fig.149B

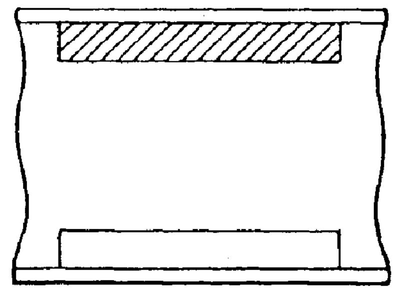


Fig.150A

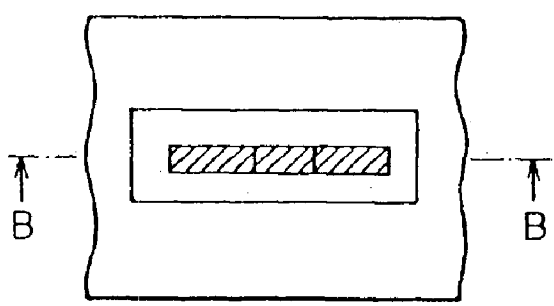


Fig.150B

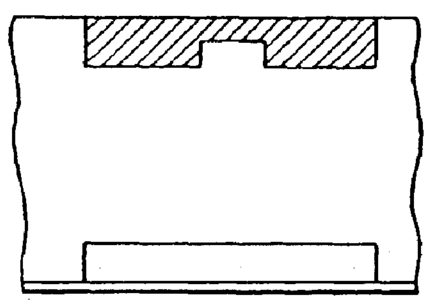


Fig.151A

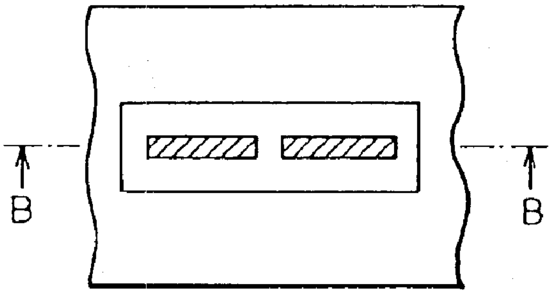


Fig.151B

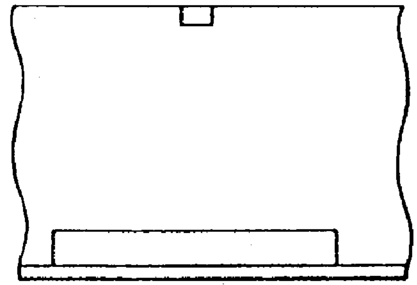


Fig.152A

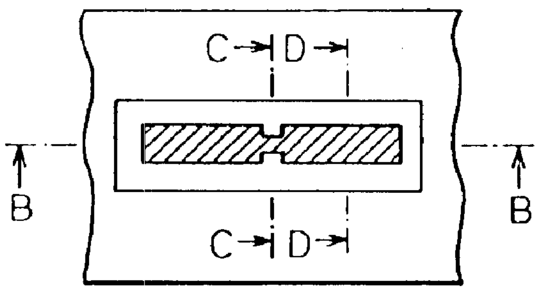


Fig.152B

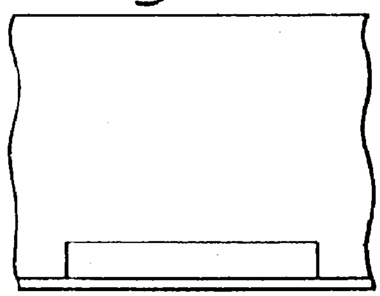


Fig.152C

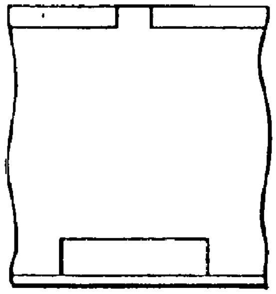


Fig.152D

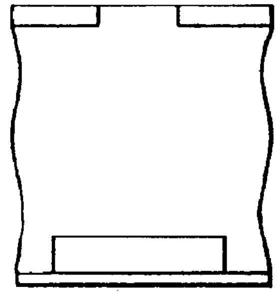


Fig.153A

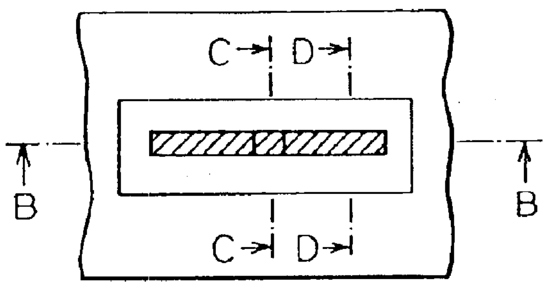


Fig.153B

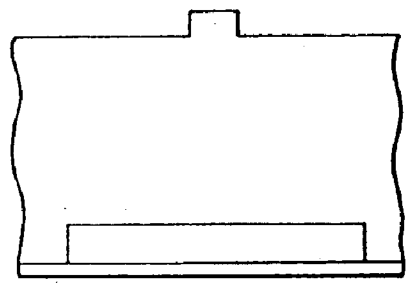


Fig.153C

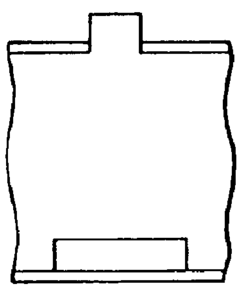


Fig.153D

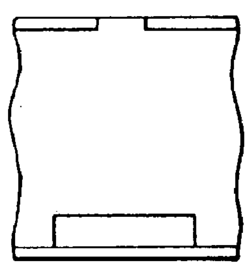


Fig.154A

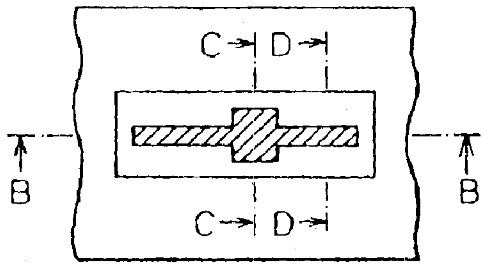


Fig.154B

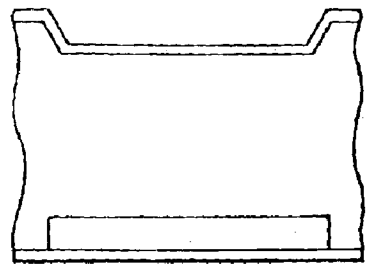


Fig.154C

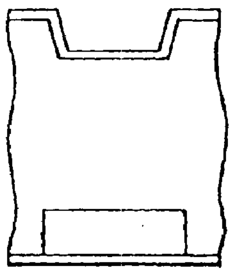


Fig.154D

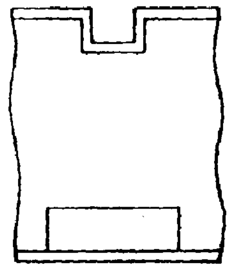


Fig.155A

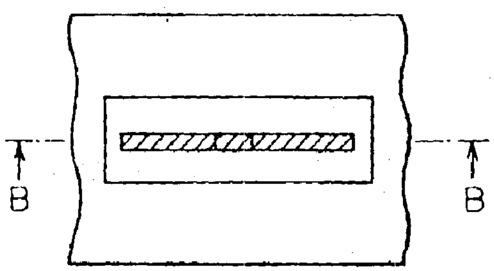


Fig.155B

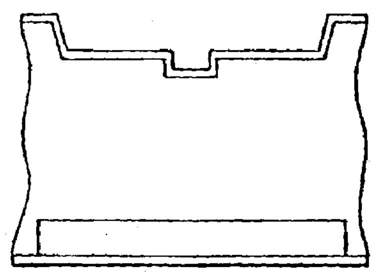


Fig.156A

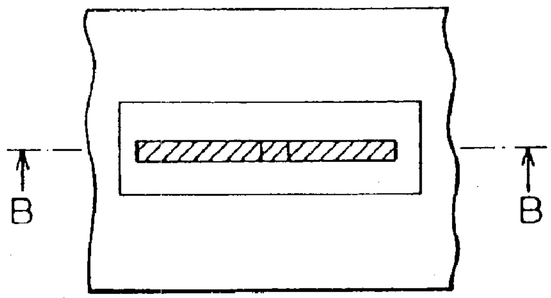


Fig.156B

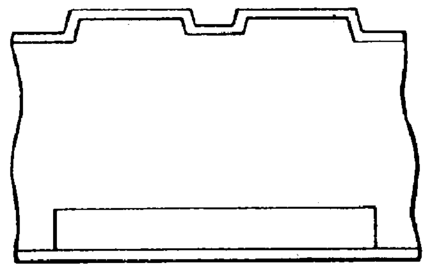


Fig.157A

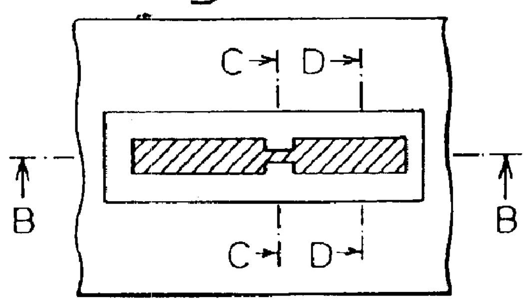


Fig.157B

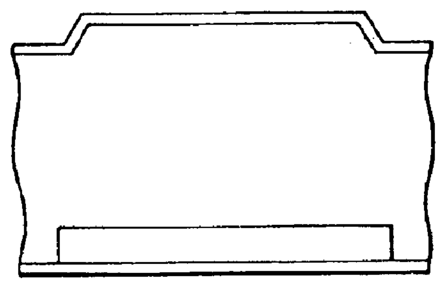


Fig.157C

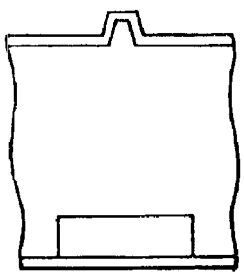
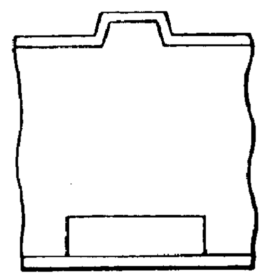


Fig.157D



LIQUID CRYSTAL DISPLAY APPARATUS HAVING ALIGNMENT CONTROL FOR BRIGHTNESS AND RESPONSE

This is a divisional of application Ser. No. 09/398,126, filed Sep. 16, 1999.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a liquid crystal display apparatus such as a TV set or a display. In particular, the present invention relates to a liquid crystal display apparatus including a vertically aligned liquid crystal.

2. Description of the Related Art

A liquid crystal display apparatus includes a liquid crystal inserted between a pair of substrates. The pair of substrates include electrodes and alignment layers, respectively. The TN liquid crystal display apparatus that finds wide applications includes horizontal alignment layers and a crystal having a positive anisotropy of its dielectric constant. When no voltage is applied, the liquid crystal is aligned substantially parallel to the horizontal alignment layers. When a voltage is applied thereto, on the other hand, the liquid crystal becomes substantially perpendicular to the horizontal alignment layers.

The TN liquid crystal display apparatus has the advantage that it can be made thin but has the disadvantage that the visual field angle is small. A method of improving this disadvantage and assuring a wide visual field angle is alignment division. In alignment division, each pixel is divided into two regions, so that the liquid crystal rises toward one side in one region and rises toward the opposite side in the other region. In this way, a wider visual field angle is assured by averaging the behavior of the liquid crystal in one pixel.

To control alignment of the liquid crystal, the alignment layers are normally rubbed. For alignment division, one region of the pixel is rubbed in a first direction using a mask, and the other region of the one pixel is rubbed in a second direction opposite to the first direction using a complementary mask. As an alternative, the whole alignment layer is rubbed in the first direction, and the one region or the other region of one pixel is selectively irradiated with ultraviolet rays using a mask thereby to create a pretilt difference between the one region and the other region.

In a liquid crystal display apparatus using horizontal alignment layers, it is necessary to carry out cleaning to clean the substrates formed having the alignment layers after rubbing. As a result, the fabrication of the liquid crystal panel is comparatively troublesome and the substrates may be polluted during the rubbing.

In a liquid crystal display apparatus using vertical alignment layers, on the other hand, the liquid crystal is aligned substantially perpendicular to the vertical alignment layers when no voltage is applied thereto and the liquid crystal is substantially parallel to the vertical alignment layers when a voltage is applied thereto. Also with a liquid crystal apparatus using the vertical alignment layers, the alignment layers are normally rubbed for controlling the alignment of the liquid crystal.

Japanese Unexamined Patent Application No. 10-185836 filed by the assignee of this application proposes a liquid crystal display apparatus capable of controlling alignment of the liquid crystal, without rubbing. This liquid crystal display apparatus is an aligned crystal display apparatus of a vertical alignment type, includes a liquid crystal having vertical alignment layers and a negative anisotropy of dielectric constant, and has alignment control structures (linearly arranged structures having projections or slits) on each of the pair of substrates for controlling the alignment of the liquid crystal.

This liquid crystal display apparatus of a vertical alignment type has the advantages that no rubbing is required and that the alignment division can be attained by the arrangement of the linearly arranged structures. With this liquid crystal display apparatus of a vertical alignment type, therefore, it is possible to secure a wide visual field angle and a high contrast. Elimination of the requirement of rubbing allows the cleaning after rubbing to be eliminated. Thus, the fabrication of a liquid crystal display apparatus is facilitated, and without any pollution on the substrates, which otherwise might occur at the time of rubbing, the reliability of the liquid crystal display apparatus is improved.

In the liquid crystal display apparatus of a vertical alignment type having alignment control structures (projections or a slits) on substrates for controlling alignment of the liquid crystal, it has been found that there are regions where the alignment of liquid crystal molecules is unstable, and there are problems regarding brightness and response speed, which must be improved.

SUMMARY OF THE INVENTION

The object of the present invention is to provide a liquid crystal display apparatus of a vertical alignment type which has improved brightness and response.

A liquid crystal display apparatus according to the present invention comprises a pair of substrates having electrodes and vertical alignment layers, a liquid crystal having a negative anisotropy of its dielectric constant inserted between the pair of substrates, and alignment control structures arranged in each of the pair of substrates for controlling the orientation of the liquid crystal. Each alignment control structure comprises a plurality of constituent units.

With this configuration, each alignment control structure comprises a plurality of constituent units, so the movement of different alignment regions is smaller at the time of voltage application and the movement is rapidly ended. As a result, it is possible to provide a liquid crystal display apparatus having a high brightness and a high response speed.

According to another aspect of the invention, there is provided a liquid crystal display apparatus comprising a pair of substrates having electrodes and vertical alignment layers, a liquid crystal having a negative anisotropy of its dielectric constant inserted between the pair of substrates, and alignment control structures arranged in each of the pair of substrates for controlling alignment of the liquid crystal. The alignment control structures of at least one of the substrates has means for forming a boundary of alignment of a first type in which the liquid crystal molecules around a point are directed to said point and means for forming boundary of orientation of a second type in which a part of the liquid crystal molecules around a point are directed to said point and the other liquid crystal molecules around said point are directed away from said point.

According to still another aspect of the invention, there is provided a liquid crystal display apparatus comprising a pair of substrates having electrodes and vertical alignment layers, a liquid crystal having a negative anisotropy of its dielectric constant inserted between the pair of substrates,

and alignment control structures arranged in each of the pair of substrates for controlling alignment of the liquid crystal. The alignment control structures of one substrate are shifted from the alignment control structures of the other substrate, as viewed in the direction normal to the one substrate, and each of one substrate and the other substrate includes means for forming a boundary of alignment of liquid crystal molecules at fixed positions with respect to the alignment control structures of the opposed substrate, at the time of voltage application thereto.

According to a further aspect of the invention, there is provided a liquid crystal display apparatus comprising a pair of substrates having electrodes and vertical alignment layers, a liquid crystal having a negative anisotropy of its dielectric constant inserted between the pair of substrates, and alignment control structures arranged in each of the pair of substrates for controlling alignment of the liquid crystal. Each alignment control structure comprises a plurality of constituent units, and the constituent units of the alignment control structures of one substrate and the constituent units of the alignment control structures of the other substrate are arranged alternately on one line, as viewed in the direction normal to one substrate.

According to a still further aspect of the invention, there is provided a liquid crystal display apparatus comprising a pair of substrates having electrodes and vertical alignment layers, a liquid crystal having a negative anisotropy of its dielectric constant inserted between the pair of substrates, and alignment control structures arranged in each of the pair of substrates for controlling alignment of the liquid crystal. Each alignment control structure has a bent portion, and an additional alignment control structure is formed on the obtuse angle side of the bent portion of the alignment control structure of the substrate having the alignment control structures.

According to a yet further aspect of the invention, there is provided a liquid crystal display apparatus comprising a pair of substrates having electrodes and vertical alignment layers, a liquid crystal having a negative anisotropy of its dielectric constant inserted between the pair of substrates, and alignment control structures arranged in each of the pair of substrates for controlling alignment of the liquid crystal. The alignment control structure has a bent portion and an additional alignment control structure is arranged on the acute angle side of the bent portion of the alignment control structure of the substrate opposed to the substrate having the alignment control structures.

According to a still further aspect of the invention, there is provided a liquid crystal display apparatus comprising a pair of substrates having electrodes and vertical alignment layers, a liquid crystal having a negative anisotropy of its dielectric constant inserted between the pair of substrates, linearly arranged structures arranged in each of the pair of substrates for controlling alignment of the liquid crystal, and polarizers arranged respectively on the outside of the pair of substrates. One polarizer has an absorption axis displaced by a predetermined angle from an orientation rotated 45 degrees with respect to an orientation where the linearly arranged structures extend.

With this configuration, brightness of the liquid crystal display apparatus can be improved. Preferably, assuming that the crossing angle between the orientation of the absorption axis of the one polarizer and the linearly arranged structures is a, the crossing angle a is adapted to satisfy the relationship, 25°<a<43° or 47°<a<65°.

According to a further aspect of the invention, there is provided a liquid crystal display apparatus comprising a pair of substrates having electrodes and vertical alignment layers, a liquid crystal having a; negative anisotropy of its dielectric constant inserted between the pair of substrates, and alignment control structures arranged in each of the pair of substrates for controlling alignment of the liquid crystal. At least one substrate has TFTs connected to electrodes, shielding areas are arranged to cover the TFTs and the areas in the neighborhood thereof, and the shielding areas are overlapped partially with a part of the alignment control structures so that the area of the alignment control structures arranged in non-shielding areas is reduced.

With this configuration, brightness of the liquid crystal display apparatus can be improved. Preferably, in the case where the alignment control structures of the substrate having the TFTS are slits, the alignment control structures of the other substrate are overlapped with the shielding areas covering the TFTs.

According to yet another aspect of the invention, there is provided a liquid crystal display apparatus comprising a pair of substrates having electrodes and vertical alignment layers, a liquid crystal having a negative anisotropy of its dielectric constant inserted between the pair of substrates, and a linearly arranged structures arranged in each of the pair of substrates for controlling alignment of the liquid crystal. There are further provided first means arranged in the linearly arranged structures of one substrate for forming a boundary of alignment of the liquid crystal, and second means arranged on the other substrate at the same position as that of the first means in the direction in which the linearly arranged structures extend.

With this configuration, the orientation of the liquid crystal can be further assured for forming a boundary of alignment of the liquid crystal.

According to a yet further aspect of the invention, there is provided a liquid crystal display apparatus comprising a pair of substrates having electrodes and vertical alignment layers, a liquid crystal having a negative anisotropy of its dielectric constant inserted between the pair of substrates, and linearly arranged structures arranged in each of the pair of substrates for controlling alignment of the liquid crystal. The linearly arranged structures of the one substrate are formed in such a manner that at least the liquid crystal molecules located at a first position are aligned in the first direction parallel to the linearly arranged structures upon application of a voltage thereto, the linearly arranged structures of the other substrate are formed in such a manner that at least the liquid crystal molecules located at the second position on the linearly arranged structures are aligned in the second direction opposite to the first direction in parallel to the linearly arranged structures upon application of a voltage thereto, and the first position and the second position are located on a line perpendicular to the linearly arranged structures.

With this configuration, the trace appearing in the display when the liquid crystal display apparatus is affected by an external pressure can be eliminated. Preferably, the linearly arranged structures of the one substrate and the linearly arranged structures of the other substrate both include means for forming a boundary of alignment of a first type with the liquid crystal molecules around a point directed to said point. As an alternative, the linearly arranged structures of the one substrate and the linearly arranged structures of the other substrate may both include means for forming a boundary of alignment of a second type with the liquid crystal molecules around a point partially directed to said point and the other liquid crystal molecules are directed away from the same point.

According to still another aspect of the invention, there is provided a liquid crystal display apparatus comprising a pair of substrates having electrodes and vertical alignment layers, a liquid crystal having a negative anisotropy of its dielectric constant inserted between the pair of substrates, alignment control structures arranged in each of the pair of substrates for controlling alignment of the liquid crystal, and an auxiliary wall structure on at least one of the substrates between the alignment control structures of the substrate pair, as viewed in the direction normal to the substrate pair.

With this configuration, the response to the voltage application can be improved. Preferably, the auxiliary wall structure is long in the direction perpendicular to the alignment control structures and is arranged at a predetermined pitch along the alignment control structures.

According to a yet further aspect of the invention, there is provided a liquid crystal display apparatus comprising a pair of substrates having electrodes and vertical alignment layers, a liquid crystal having a negative anisotropy of its dielectric constant inserted between the pair of substrates, alignment control structures arranged in each of the pair of substrates for controlling alignment of the liquid crystal, and liquid crystal inclined orientation control means arranged between the alignment control structures of the substrate pair in which a parameter changes in one direction from one of the alignment control structures.

With this configuration, response to the voltage application can be improved.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will become more apparent from the following description of the preferred embodiments, with reference to the accompanying drawings, in which:

FIG. **1** is a schematic cross-sectional view showing a liquid crystal display apparatus;

FIG. **2** is a schematic cross-sectional view showing a vertical alignment type liquid crystal display apparatus having alignment control structures for controlling alignment of the liquid crystal;

FIG. **3** is a plan view showing one pixel and the alignment control structures;

FIG. **4**A is a plan view of the linearly arranged structures of FIGS. **2** and **3** with liquid crystal molecules falling based on the linearly arranged structures at the time of voltage application;

FIG. **4**B is a cross-sectional view taken along the line IVB—IVB in FIG. **4**A;

FIG. **5** is a plan view showing another example of the alignment control structures;

FIG. **6** is a schematic cross-sectional view showing a liquid crystal display apparatus in which the alignment control structures of a pair of the substrates are both projections;

FIG. **7** is a schematic cross-sectional view showing a liquid crystal apparatus in which the alignment control structures of one substrate are projections and the alignment control structures of the other substrate are slit structures;

FIG. **8** is a schematic cross-sectional view showing a liquid crystal display apparatus in which the alignment control structures of a pair of substrates are both slit structures;

FIG. **9** is a cross-sectional view showing an example of the alignment control structures in the form of projections;

FIG. **10** is a cross-sectional view showing an example of the alignment control structure in the form of slit structures;

FIG. **11** is a view explaining a problem of the alignment of the liquid crystal display apparatus having alignment control structures;

FIG. **12** is a view showing the transmittance in several areas of FIG. **11**;

FIG. **13** is a view showing an overshoot of brightness;

FIG. **14** is a view showing alignment control structures according to the first embodiment of the present invention;

FIG. **15** is a view showing a modification of the alignment control structures;

FIG. **16** is a view showing a modification of the alignment control structures;

FIG. **17** is a view showing a modification of the alignment control structures;

FIG. **18** is a view showing a modification of the alignment control structures;

FIG. **19** is a view showing a modification of the alignment control structures;

FIG. **20** is a view showing a modification of the alignment control structures;

FIG. **21** is a view showing a modification of the alignment control structures;

FIG. **22** is a view showing the pixel electrode and the slit structure of FIG. **21**;

FIGS. **23**A to **23**E are views explaining the formation of the alignment control structure in the form of projections;

FIG. **24** is a view showing the alignment of the liquid crystal of the liquid crystal display apparatus having the alignment control structures;

FIG. **25** is a view showing a display characteristic in the configuration of FIG. **24**;

FIG. **26** is a view showing the alignment of the liquid crystal of the liquid crystal display apparatus having the alignment control structures including a plurality of constituent units;

FIG. **27** is a view showing a display characteristic in the configuration of FIG. **26**;

FIG. **28** is a view showing the alignment of the liquid crystal in the liquid crystal display apparatus having alignment control structures according to the second embodiment of the present invention;

FIG. **29** is a view showing a display characteristic in the configuration of FIG. **28**;

FIG. **30** is a view showing the feature of a boundary of alignment of a first type and the feature of a boundary of alignment of a second type;

FIG. **31** is a plan view showing a specific example of the alignment control structures of FIG. **28**;

FIG. **32** is a cross-sectional view through the alignment control structures of FIG. **31**;

FIG. **33** is a plan view showing a modification of the alignment control structures;

FIG. **34** is a cross-sectional view through the structures of FIG. **33**;

FIGS. **35**A and **35**B are plan views showing modifications of the alignment control structrures;

FIG. **36** is a plan view showing a modification of the alignment control structures;

FIG. **37** is a plan view showing a modification of the alignment control structures;

FIGS. **38**A and **38**B are cross-sectional views of a portion of a liquid crystal display apparatus near the edge of the pixel electrode;

FIGS. **39**A and **39**B are views showing the alignment of the liquid crystal at the edge of the pixel electrode of FIGS. **38**A and **38**B;

FIG. **40** is plan view showing a modification of the alignment control structures;

FIG. **41** is a plan view showing a modification of the alignment control structures;

FIG. **42** is a plan view showing a modification of the alignment control structures;

FIG. **43** is a plan view showing the alignment control structures according to the third embodiment of the present invention;

FIG. **44** is a cross-sectional view of the liquid crystal display apparatus passing through the alignment control structures of FIG. **43**;

FIG. **45** is a view showing the alignment of the liquid crystal in the neighborhood of the alignment control structures of FIG. **44**;

FIG. **46** is a view showing the alignment of the liquid crystal in the neighborhood of the alignment control structures according to the first embodiment;

FIG. **47**A is a cross-sectional view showing a modification of the means for controlling the boundary and the alignment control structures;

FIG. **47**B is a schematic perspective view of FIG. **47**A;

FIG. **47**C is a schematic plan view of FIG. **47**B;

FIG. **48** is a cross-sectional view showing a modification of the means for controlling the alignment in the boundary and the alignment control structures;

FIG. **49** is a cross-sectional view showing a modification of the means for controlling the alignment in the boundary and the alignment control structures;

FIG. **50** is a cross-sectional view showing a modification of the means for controlling the alignment in the boundary and the alignment control structures;

FIG. **51** is a plan view showing a modification of the means for controlling the alignment in the boundary and the alignment control structures;

FIG. **52** is a cross-sectional view taken along line **52—52** in FIG. **51**;

FIG. **53** is a cross-sectional view taken along the line **53—53** in FIG. **51**;

FIG. **54** is a plan view showing a modification of the means for controlling the alignment in the boundary and the alignment control structures;

FIG. **55** is a cross-sectional view of the liquid crystal display apparatus through the alignment control structures of FIG. **54**;

FIG. **56** is a plan view showing a modification of the means for controlling the alignment in the boundary and the alignment control structures;

FIG. **57** is a cross-sectional view of the liquid crystal display apparatus through the alignment control structures of FIG. **56**;

FIG. **58** is a plan view showing the alignment control structures according to the fourth embodiment;

FIG. **59** is a schematic cross-sectional view of the liquid crystal display apparatus taken along the line **59—59** of FIG. **58**;

FIG. **60** is a plan view showing a modification of the alignment control structures;

FIG. **61** is a plan view showing a pixel electrode having the slit structure of FIG. **60**;

FIG. **62** is a plan view showing a modification of the alignment control structures;

FIG. **63** is a plan view showing a modification of the alignment control structures;

FIG. **64** is a plan view showing a modification of the alignment control structures;

FIG. **65** is a plan view showing a modification of the alignment control structures;

FIG. **66** is a plan view showing the alignment control structures according to the fifth embodiment of the present invention;

FIG. **67** is a plan view showing a typical example of the alignment control structures having bent portions;

FIG. **68** is a view explaining the problem of the liquid crystal display apparatus having the alignment control structures of FIG. **67**;

FIG. **69** is a plan view showing a modification of the alignment control structures;

FIG. **70** is a plan view showing a modification of the alignment control structures;

FIG. **71** is a plan view showing a modification of the alignment control structures;

FIG. **72** is a plan view showing a modification of the alignment control structures;

FIG. **73** is a plan view showing a modification of the alignment control structures;

FIG. **74** is a plan view showing a modification of the alignment control structures;

FIG. **75** is a view showing the relationship between the alignment control structures and the polarizers of the liquid crystal display apparatus according to the sixth embodiment of the present invention;

FIGS. **76**A to **76**C are views showing the display brightness in the configuration of FIG. **75**;

FIG. **77** is a view showing the relationship between the angle of the director of the liquid crystal and frequency thereof for minor areas in the liquid crystal display apparatus having the alignment control structures for controlling the alignment of the liquid crystal;

FIG. **78** is a view showing the relationship between the alignment control structures and the polarizers of the liquid crystal display apparatus according to a modification of the embodiment of FIG. **75**;

FIG. **79** is a cross-sectional view of the liquid crystal display apparatus of FIG. **78**;

FIG. **80** is a view showing the relationship between the alignment control structures and the polarizers of the liquid crystal display apparatus according to a modification of the embodiment of FIG. **75**;

FIG. **81** is a cross-sectional view of the liquid crystal display apparatus of FIG. **80**;

FIG. **82** is a view showing the alignment control structures of a liquid crystal display apparatus according to the seventh embodiment of the present invention;

FIG. **83** is a cross-sectional view taken along the line **83—83** in the liquid crystal display apparatus of FIG. **82**;

FIG. **84** is a view showing a more specific example of the alignment control structures of FIG. **82**;

FIG. **85** is a plan view showing a comparative example of the alignment control structures of FIG. **82**;

FIG. **86** is a view showing a modification of the alignment control structures of FIG. **28**;

FIG. **87** is a cross-sectional view taken along the line **87—87** of the liquid crystal display apparatus having the alignment control structures of FIG. **86**;

FIG. **88** is a view showing the alignment control structures of the liquid crystal display apparatus according to the eighth embodiment of the present invention;

FIG. **89** is a cross-sectional view taken along the line **89**—**89** of a liquid crystal display apparatus having the linear wall structure of FIG. **88**;

FIG. **90** is a view showing a modification of the alignment control structures of FIG. **88**;

FIG. **91** is a cross-sectional view through the liquid crystal display apparatus having the alignment control structures of FIG. **89**;

FIG. **92** is a view showing a modification of the alignment control structures of FIG. **88**;

FIG. **93** is a cross-sectional view of the alignment control structures of FIG. **92**;

FIG. **94** is a view showing a modification of the alignment control structures of FIG. **93**;

FIG. **95** is a view showing a modification of the alignment control structures of FIG. **88**;

FIG. **96** is a cross-sectional view passing through the liquid crystal display apparatus having the alignment control structures of FIG. **95**;

FIG. **97** is a view showing a modification of the alignment control structures of FIG. **88**;

FIG. **98** is a view showing a modification of the alignment control structures of FIG. **88**;

FIG. **99** is a view showing the alignment control structures of the liquid crystal display apparatus according to the ninth embodiment of the present invention;

FIG. **100** is a view showing a modification of the alignment control structures of FIG. **99**;

FIG. **101** is a view explaining the problem of pressing, by finger-pressure, the liquid crystal display apparatus having the alignment control structure;

FIG. **102** is a view showing an example liable to pose a problem when pressed by a finger;

FIG. **103** is a view showing an example of means for forming boundary of first type of FIG. **99**;

FIG. **104** is a perspective view illustrating the liquid crystal display apparatus having means for forming a boundary of first type of FIG. **103**;

FIG. **105** is a view showing an example of means for forming a boundary of second type of FIG. **99**;

FIG. **106** is a perspective view illustrating the liquid crystal display apparatus having means for forming a boundary of second type of FIG. **105**;

FIG. **107** is a view showing an example of means for forming a boundary of first type of FIG. **99**;

FIG. **108** is a view showing an example of means for forming a boundary of second type of FIG. **99**;

FIG. **109** is a view showing the alignment control structures of the liquid crystal display apparatus according to the tenth embodiment of the present invention;

FIG. **110** is a cross-sectional view taken along the line **110**—**110** of the liquid crystal display apparatus of FIG. **109**;

FIG. **111** is a view showing a modification of the liquid crystal display apparatus of FIG. **109**;

FIG. **112** is a view showing a modification of the liquid crystal display apparatus of FIG. **109**;

FIG. **113** is a cross-sectional view taken along the line **113**—**113** of the liquid crystal display apparatus of FIG. **112**;

FIG. **114** is a view showing a modification of the liquid crystal display apparatus of FIG. **109**;

FIG. **115** is a cross-sectional view taken along the line **115**—**115** of the liquid crystal display apparatus of FIG. **114**;

FIGS. **116**A to **116**G are views showing a method of fabricating a substrate having the alignment control structures and auxiliary wall structures;

FIGS. **117**A to **117**E are views showing another example of the method of fabricating a substrate having the alignment control structures and auxiliary wall structures;

FIG. **118** is a view showing a response when the distance between the auxiliary structures (slits) is changed while fixing the width of the auxiliary wall structures (slits) in the liquid crystal display apparatus of FIG. **111**;

FIG. **119** is a view showing a response when the width of the auxiliary structures (slits) is changed while fixing the distance between the auxiliary wall structures (slits) in the liquid crystal display apparatus of FIG. **111**;

FIG. **120** is a view showing a response when the distance between the auxiliary structures (slits) is changed while fixing the size of the auxiliary wall structures (slits) in the liquid crystal display apparatus of FIG. **112**;

FIG. **121** is a view showing a response with the size of the auxiliary structures (projections) is changed while fixing the distance between the auxiliary wall structures (projections) in the liquid crystal display apparatus of FIG. **112**;

FIG. **122** is a view showing the alignment control structures of the liquid crystal display apparatus according to the eleventh embodiment of the present invention;

FIG. **123** is a view showing a modification of the liquid crystal display apparatus of FIG. **122**;

FIGS. **124**A to **124**E are views showing a method of fabricating the liquid crystal display apparatus of FIG. **122**;

FIGS. **125**A to **125**E are views showing a method of fabricating the liquid crystal display apparatus of FIG. **123**;

FIG. **126** is a view showing a modification of the liquid crystal display apparatus of FIG. **122**;

FIG. **127** is a view showing a modification of the liquid crystal display apparatus of FIG. **122**;

FIG. **128** is a view showing a modification of the liquid crystal display apparatus of FIG. **122**;

FIG. **129** is a view showing a modification of the liquid crystal display apparatus of FIG. **122**;

FIG. **130** is a view showing a modification of the liquid crystal display apparatus of FIG. **122**;

FIG. **131** is a view showing a modification of the liquid crystal display apparatus of FIG. **122**;

FIG. **132** is a view showing a modification of the liquid crystal display apparatus of FIG. **122**;

FIGS. **133**A to **133**C are views showing modifications of the liquid crystal display apparatus of FIG. **122**;

FIGS. **134**A to **134**C are views showing modifications of the liquid crystal display apparatus of FIG. **122**;

FIGS. **135**A and **135**B are views showing a modification of the alignment control structures of FIG. **43**;

FIGS. **136**A and **136**B are views showing a modification of the alignment control structures of FIG. **43**;

FIGS. **137**A and **137**B are views showing a modification of the alignment control structures of FIG. **43**;

FIGS. **138**A to **138**E are views showing a modification of the alignment control structures of FIG. **43**;

FIGS. **139**A and **139**B are views showing a modification of the alignment control structures of FIG. **43**;

FIGS. **140**A and **140**B are views showing a modification of the alignment control structures of FIG. **43**;

FIGS. **141**A to **141**D are views showing a modification of the alignment control structures of FIG. **43**;

FIGS. **142**A to **142**D are views showing a modification of the alignment control structures of FIG. **43**;

FIGS. **143**A to **143**D are views showing a modification of the alignment control structures of FIG. **43**;

FIGS. **144**A and **144**B are views showing a modification of the alignment control structures of FIG. **43**;

FIGS. **145**A and **145**B are views showing a modification of the alignment control structures of FIG. **43**;

FIGS. **146**A to **146**D are views showing a modification of the alignment control structures of FIG. **43**;

FIGS. **147**A and **147**B are views showing a modification of the alignment control structures of FIG. **43**;

FIGS. **148**A and **148**B are views showing a modification of the alignment control structures of FIG. **43**;

FIGS. **149**A and **149**B are views showing a modification of the alignment control structures of FIG. **43**;

FIGS. **150**A and **150**B are views showing a modification of the alignment control structures of FIG. **43**;

FIGS. **151**A and **151**B are views showing a modification of the alignment control structures of FIG. **43**;

FIGS. **152**A to **152**D are views showing a modification of the alignment control structures of FIG. **43**;

FIGS. **153**A to **153**D are views showing a modification of the alignment control structures of FIG. **43**;

FIGS. **154**A to **154**D are views showing a modification of the alignment control structures of FIG. **43**;

FIGS. **155**A and **155**B are views showing a modification of the alignment control structures of FIG. **43**;

FIGS. **156**A and **156**B are views showing a modification of the alignment control structures of FIG. **43**; and

FIGS. **157**A to **157**D are views showing a modification of the alignment control structures of FIG. **43**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention will now be explained with reference to the preferred embodiments. FIG. **1** is a schematic cross-sectional view showing a liquid crystal display apparatus according to the present invention. In FIG. **1**, the liquid crystal display apparatus **10** includes a pair of transparent glass substrates **12** and **14**, and a liquid crystal **16** having a negative anisotropy of its dielectric constant inserted between the glass substrates **12** and **14**. The first glass substrate **12** has an electrode **18** and a vertical alignment layer **20**, and the second glass substrate **14** has an electrode **22** and a vertical alignment layer **24**. Further, a polarizer **26** is arranged on the outside of the first glass substrate **2**, and a polarizer **28** is arranged on the outside of the second glass substrate **14**. To simplify the explanation, the first glass substrate **12** will be called the upper substrate, and the second glass substrate **14** will be called the lower substrate.

In the case where the upper substrate **12** is configured as a color filter substrate, the upper substrate **12** further includes a color filter and a black mask. In this case, the electrode **18** is a common electrode. In the case where the lower substrate is configured as a TFT substrate, on the other hand, this lower substrate **12** includes an active matrix drive circuit together with the TFTs. In this case, the electrode **22** comprises a pixel electrodes.

FIG. **2** is a schematic cross-sectional view showing the liquid crystal display apparatus of a vertical orientation type having alignment control structures for controlling alignment of the liquid crystal. For simplicity, the electrodes **18** and **22** and the alignment layers **20** and **24** of FIG. **1** are not shown in FIG. **2**. In FIG. **2**, the upper substrate **12** has projections **30** protruded toward the lower substrate **14** as alignment control structures. In a similar fashion, the lower substrate **14** has projections **32** protruded toward the upper substrate **12** as alignment control structures. The projections **30** and **32** extend linearly in the direction perpendicular to the page of FIG. **2**.

FIG. **3** is a plan view of the projections **30** and **32** shown from the direction of arrow III of FIG. **2**. FIG. **3** further shows the portion of one pixel of the active matrix drive circuit. The active matrix drive circuit includes gate bus lines **36**, drain bus lines **38**, TFTs **40** and pixel electrodes **22**. The projection **30** of the upper substrate **12** passes through the center of the pixel electrode **22**, and the projections **32** of the lower substrate **12** pass through the gate bus lines **36**. In this way, the projections **30** and **32** extend, in the top plan view, in parallel to each other and are arranged alternately. The example of FIG. **3**, however, is a very simple one, to which the arrangement of the projections **30** and **32** is not limited.

As shown in FIG. **2**, in the case where the liquid crystal **16** having a negative anisotropy of dielectric constant is arranged between the vertical alignment layers **20** and **24**, the liquid crystal molecules **16**A are aligned in the direction perpendicular to the vertical alignment layers **20** and **24** when no voltage is applied thereto. In the neighborhood of the projections **30** and **32**, the liquid crystal molecules **16**B are aligned in the direction perpendicular to the projections **30** and **32**. The projections **30** and **32** include slopes, and therefore the liquid crystal molecules **16**B aligned in the direction perpendicular to the projections **30** and **32** are aligned at an angle to the vertical alignment layers **20** and **24**.

Upon application of the voltage to the liquid crystal **16**, the liquid crystal **16** having a negative anisotropy of its dielectric constant is aligned perpendicular to the electric field, and therefore the liquid crystal molecules lie substantially parallel to the substrate surfaces (vertical alignment layers **20** and **24**). Normally, if the vertical alignment layers **20** and **24** are not rubbed, the direction in which the liquid crystal molecules lie is not decided, so the behavior of the liquid crystal is unstable. If the projections **30** and **32** extending in parallel to each other are provided as in this invention, however, the liquid crystal molecules **16**B in the neighborhood of these projections **30** and **32** are aligned at an angle to the vertical alignment layers **20** and **24** as if pretilted, and therefore the direction in which the liquid crystal molecules **16**B lie is determined by the time of voltage application thereto.

Taking as an example the liquid crystal molecules between the projection **30** on the left side on the upper substrate **14** and the projection **32** on the lower left side below the projection **30** in FIG. **2**, the liquid crystal molecules **16**B between these projections **30** and **32** are aligned from the upper right toward the lower left, and therefore, at the time of voltage application thereto, the liquid crystal molecules **16**B fall in the direction parallel to the vertical alignment layers **20**, **24** while rotating in the clockwise direction. As a result, the liquid crystal molecules **16**A between these projections **30** and **32** fall in the direction parallel to the vertical alignment layers **20, 24** while rotating in the clockwise direction according to the behavior of the liquid crystal molecules **16**B. In a similar fashion, among the liquid crystal molecules between the projection **30** on the

left side of the upper substrate **14** and the projection **32** on the lower right below the projection **30** in FIG. **2**, the liquid crystal molecules **16**B between the projections **30** and **32** are aligned from the upper left side down rightward, and therefore fall in the direction parallel to the vertical alignment layers **20** and **24** while rotating in the counterclockwise direction at the time of voltage application thereto. As a result, the liquid crystal molecules **16**A between these projections **30** and **32** fall parallel to the vertical alignment layers **20** and **24** while rotating in the counterclockwise direction according to the behavior of the liquid crystal molecules **16**B.

FIGS. **4**A and **4**B are views showing the liquid crystal molecules **16**A falling at the time of voltage application thereto in accordance with the arrangement of the projections **30** and **32** of FIGS. **2** and **3**. FIG. **4**A is a plan view and FIG. **4**B a cross-sectional view taken in line IVB—IVB. The liquid crystal molecules **16**A on one side of the projection **30** of the upper substrate **12** fall toward the projection **30** while rotating in the clockwise direction (the direction along arrow X), while the liquid crystal molecules **16**A on the other side of the projection **30** of the upper substrate **12** fall toward the projection **30** while rotating in the counterclockwise direction (the direction along arrow Y). By the way, in FIG. **4**A, the liquid crystal molecules **16**A are aligned perpendicular to the page of FIG. **4**A in the absence of a voltage applied thereto. In this way, the liquid crystal alignment can be controlled without rubbing, and a plurality of areas having different directions of alignment of liquid crystal molecules are created in one pixel. Therefore, the alignment division is attained, thereby realizing a liquid crystal display apparatus having a wide angular range with a superior visual field.

FIG. **5** is a plan view showing another example of the projections (alignment control structures) **30** and **32**. The projections **30** and **32** extend in parallel to each other while being bent at the same time. In other words, the projections **30** and **32** are bent in zigzag fashion in parallel to each other. In this example, the liquid crystal molecules **16**C and **16**D on either side of the small, straight portion of the projections **30** and **32** are aligned in opposite directions, and the liquid crystal molecules **16**E and **16**F on the either side of the next small, straight portion of the bend of the projections **30** and **32** are aligned in opposite directions. The liquid crystal molecules **16**C and **16**D are rotated by 90 degrees with respect to the liquid crystal molecules **16**E, **16**F. As a result, the alignment division with four regions of different liquid crystal alignments in one pixel can be attained for a further improved visual field angle characteristic.

FIG. **6** is a view illustrating a liquid crystal display apparatus in which the alignment control structures are formed by the projections **30** and **32**. In FIG. **6**, the electrode **18** arranged on the upper substrate **12** and the electrode **22** arranged on the lower substrate **14** are shown. The projections **30** and **32** are formed as dielectric members on the electrodes **1**B and **22**, respectively. Numeral **42** designates an electric field in the neighborhood of the projections **30** and **32**. The projections **30** and **32** are made of dielectric material, and therefore, the electric field **42** in the neighborhood of the projections **30** and **32** is an oblique one. Thus, at the time of voltage application thereto, the liquid crystal molecules fall perpendicular to the electric field **42** as indicated by arrows. The direction in which the liquid crystal molecules lie by the oblique electric field is the same as the direction in which the liquid crystal molecules lie by the slopes of the projections **30** and **32**.

FIG. **7** is a schematic cross-sectional view showing a liquid crystal display apparatus in which the alignment control structures of the lower substrate **14** are the projections **32** and the alignment control structures of the upper substrate **12** are slit structures **44**. The slit structures **44** includes the slits of the electrode **18** of the upper substrate **12**. Actually, the vertical alignment layer **20** (not shown in FIG. **7**) covers the electrode **18** having the slits. Therefore, the vertical alignment layer **20** is recessed at the positions thereof corresponding to the slits of the electrode **18**. The slit structures **44** each include the slit in the electrode **18** and the recessed portion of the vertical alignment layer **20**. These slit structures **44** extend linearly in a similar fashion to the projections **30** of FIG. **6**.

In the neighborhood of each slit structure **44**, an oblique electric field **42** is formed between the electrode **18** of the upper substrate **12** and the electrode **22** of the lower substrate **14**. This oblique electric field **42** is similar to the oblique electric field **42** formed in the neighborhood of the projections **30** in FIG. **6**, and the liquid crystal molecules fall in accordance with the oblique electric field **42** at the time of voltage application thereto. In this case, the manner in which the liquid crystal molecules fall is the same as the manner in which the liquid crystal molecules fall in the presence of the projections **30**. Thus, in the same manner that alignment of the liquid crystal is controlled by the combination of the projections **30** and **32** as shown in FIG. **6**, alignment of the liquid crystal can be also controlled by the combination of the slit structures **44** and the projections **32**.

FIG. **8** is a schematic cross-sectional view showing a liquid crystal display apparatus in which the alignment control structures of the upper substrate **12** and the lower substrate **14** are both slit structures **44** and **46**, respectively. Each slit structure **44** extends linearly in similar fashion to the projections **30** of FIG. **6**, and the slit structures **46** extend linearly in a similar manner to the projections **32** of FIG. **6**. In the neighborhood of the slit structures **44** and **46**, an oblique electric field **42** is formed between the electrode **18** of the upper substrate **12** and the electrode **22** of the lower substrate **14**. This oblique electric field **42** is similar to the oblique electric field **42** formed in the neighborhood of the projections **30** and **32** in FIG. **6**, so that the liquid crystal molecules fall in accordance with the oblique electric field **42** at the time of voltage application thereto. In this case, the manner in which the liquid crystal molecules fall is the same as the manner in which the liquid crystal molecules fall in the presence of the projections **30** and **32**. Thus, in the same manner that alignment of the liquid crystal is controlled by the combination of the projections **30** and **32** as shown in FIG. **6**, alignment of the liquid crystal can be controlled by the combination of the slit structures **44** and **46**.

As a result, alignment of the liquid crystal can be controlled in the same way by the projections **30** and **32** as by the slit structures **44** and **46**. Therefore, the projections **30** and **32** and the slit structures **44** and **46** can be understood in common terms of alignment control structures (or linearly arranged structures).

FIG. **9** is a cross-sectional view showing an example of the alignment control structures (linearly arranged structures) constituting the projections **30** (**32**). The projections **30** are formed in the following manner, for example. The lower substrate **14** is formed with the electrodes **22** together with the active matrix. Dielectric members **30**A to constitute projections are formed on the electrodes **22**. The dielectric members **30**A are formed by coating a resist and patterning it. The vertical alignment layer **24** is formed on the dielectric member **30**A and the electrode **22**. In this way, the projections **30** are formed.

FIG. **10** is a cross-sectional view showing an example of the alignment control structures (linearly arranged structures) in the form of the slit structures **44** (**46**). The slit structures **44** are formed in the following manner, for example. After forming a color filter and a black matrix, etc., the electrode **18** is formed on the upper substrate **14**. The electrode **18** is patterned thereby to form the slits **18**A. A vertical alignment layer **20** is formed on the electrode **18** having the slits **18**A. In this way, the slit structures **44** are formed.

FIG. **11** is a view explaining the problem of alignment of the liquid crystal display apparatus having the linearly arranged structures. Although the linearly arranged structures are described hereinafter primarily as the projections **30** and **32**, the slit structures (sometimes simply called the slits) **44** and **46** may be used in place of the projections **30** and **32** with equal effect.

FIG. **11** shows the state similar to that of FIG. **4**. (FIG. **4**; however, shows only the liquid crystal molecules **16**A in the gap between the projections **30** and **32**, while FIG. **11** shows the liquid crystal molecules existing in the gap between the projections **30** and **32** and the liquid crystal molecules existing on and in the neighborhood of the projections **30** and **32**. Also, in FIG. **11**, the projection **32** of the lower substrate **14** is located at the center.) Numeral **48** designates the arrangement of the polarizers **26** and **28**. The polarizers **26** and **28** are arranged at an angle of 45 degrees to the projections **30** and **32**.

As described above, at the time of voltage application thereto, the liquid crystal molecules **16**A existing in the gap between the projections **30** and **32** come to lie perpendicular to the projections **32** on either side of the projection **32** of the lower substrate (or the projection **30** of the upper substrate **12**) in opposite directions. The liquid crystal molecules on and in the neighborhood of the projections **30** and **32**, which are located between the liquid crystal molecules **16**A lying in opposite directions, lie continuously with these liquid crystal molecules **16**A. The liquid crystal molecules all come to be aligned in a plane parallel to the page of FIG. **11**. In this case, the liquid crystal molecules just above the projection **32** may fall rightward or fall leftward. It is uncertain whether the liquid crystal molecules located just above the projections **32** fall rightward or leftward. For this reason, an alignment condition in which the liquid crystal molecules have fallen rightward and another alignment condition in which the liquid crystal molecules have fallen leftward coexist on the same projection **32**. At a place where these two alignment conditions are in contact with each other, a boundary of alignment of the liquid crystal (singular point in director field) is formed. A plurality of boundaries exist on the single projection **32**.

Also, in the case where the liquid crystal on the projection **30** of the upper substrate **12** is aligned in the same manner as those on the projection **32** of the lower substrate **14** (in the area C, for example), the alignment between the projections **30** and **32** assumes a bent form. In the case where the liquid crystal is differently oriented on the projection **30** of the upper substrate **12** from those on the projection **32** of the lower substrate **32** (in the area A, for example), on the other hand, the alignment between the projections **30** and **32** assumes a spray form. Specifically, two types of alignment conditions coexist between the projections **30** and **32**, and a boundary is formed between these areas of different alignment.

In more detail, even an alignment in the spray form, for example, is slightly different when the upper and lower

substrates **12** and **14** are misaligned. The result is different angles of the polarizers **26** and **28** at which the transmittance is maximum in the respective areas. This condition was actually measured by rotating the polarizers **26** and **28** in several areas. In FIG. **11**, area A shows that the polarizers **26** and **28** have been rotated by about −13 degrees with respect to a normal arrangement **48**. The area B shows that the polarizers **26** and **28** have been rotated by −4 degrees with respect to the normal arrangement **48**. The area C, on the other hand, shows that the polarizers **26** and **28** have been rotated by +2 degrees with respect to the normal arrangement **48**.

FIG. **12** is a view showing transmittance measured in the areas A, B and C of FIG. **11**. The curve A represents the measurement in the area A of FIG. **11**, the curve B the measurement in the area B of FIG. **11**, and the curve C the measurement in the area C of FIG. **11**. The curve A indicates that a considerably high transmittance is obtained at an angle of the polarizers **26** and **28** considerably displaced from the normal arrangement (45 degrees with respect to the projections **30** and **32**), while in the case where the polarizers **26** and **28** are in the normal arrangement **48** (45 degrees with respect to the projections **30** and **32**), light cannot be substantially transmitted. The curve B indicates that a comparatively high transmittance is obtained in the case where the polarizers **26** and **28** are located at an angle somewhat displaced from the normal arrangement **48** (45 degrees with respect to the projections **30**, **32**). The curve C shows that some degree of transmittance can be secured in the case where the polarizers **26** and **28** are in the normal arrangement **48** (45 degrees with respect to the projections **30**, **32**). In this way, the use of the projections **30** and **32** produces a plurality of areas of different transmittance characteristics.

FIG. **13** is a view showing the change in transmittance after voltage application. In the case where areas of different alignments exist as described with reference to FIGS. **11** and **12**, a phenomenon called overshoot occurs immediately after voltage application. Specifically, the transmittance increases greatly, for example, 1000 ms after voltage application, and then, gradually decreases to a predetermined value where it comes into equilibrium. The overshoot is expressed by the degree the white brightness has increased from the transmittance in equilibrium. The overshoot (%) is defined as $(Y-X)/X\times100$, where the initial brightness is X and the brightness in equilibrium is Y.

As shown in FIG. **11**, if the areas A, B and C having different transmittances exist, the liquid crystal in the areas A, B and C continues to move in the respective areas after voltage application, and the liquid crystal in adjacent areas affects each other, so that the areas A, B and C themselves continue to move (i.e. the boundaries between areas A, B and C continue to move). As a result, the transmittance increases and so does the overshoot. The overshoot is a cause of the afterimage, often leading to the deterioration of the display quality. Also, in the presence of areas A, B and C having different features, the display performance may develop a difference, thereby making it impossible to obtain a predetermined quality.

For this reason, it is desired to control alignment of the liquid crystal on the projections **30** and **32** to prevent the liquid crystal in areas having different transmittances from continuing to move persistently and thereby to improve brightness and response.

FIG. **14** is a view showing an example of the projections (linearly arranged structures) **30** and **32** according to the first embodiment of the present invention. Slit structures **44** and

46 can of course be used in place of the projections **30** and **32** as the linearly arranged structures.

The liquid crystal display apparatus has the projections **30** of the upper substrate **12** and the projections **32** of the lower substrate **14**, as described above. Each projection **30** or **32** is formed of a plurality of constituent units **30S** or **32S**. The constituent units **305** or **32S** have a substantially uniform shape, and are distinguished from each other by a change in the shape or cutting. In the example of FIG. **14**, two adjacent constituent units **30S** or **32S** are connected by a narrow portion. Also, the constituent units **30S** of the projections **30** of the upper substrate **12** and the constituent units **32S** of the projection **32** of the lower substrate **14** extend in parallel to each other, and the constituent units of the projections **30** of the upper substrate **12** and the corresponding constituent units of the projections **325** of the lower substrate **14** are arranged at such positions as to be overlapped with each other.

As described above, each projection **30** or **32** is formed of a plurality of the constituent units **30S** or **32S**, respectively and, therefore, there is less likelihood of forming a plurality of areas A, B and C having different transmittances as shown in FIG. **11** within each constituent unit **30S** or **32S**. Also, the areas A, B and C are prevented from continuously moving (the boundaries between the areas A, B and C are prevented from continuing to move), so that the liquid crystal comes to be stably aligned in the horizontal state within a shorter time. As a result, overshoot is reduced, thereby improving both the brightness and the response speed. Even if there are areas with a large transmittance loss, the effect thereof can be offset by the presence of a multiplicity of small areas with a small transmittance loss. For this purpose, each projection **30** or **32** desirably includes as many constituent units **30S** or **32S** as possible, respectively. Preferably, the length of the constituent units **30S** or **32S** is not less than the length of the gap between the projections **30** and **32** of the pair of substrates **12** land **14**, and not more than 200 μm.

FIG. **15** is a view showing a modification of the projections **30** and **32**. The projections **30** and **32** are each configured of a plurality of constituent units **30S** and **32S**. In this example, the projections **30** and **32** are cut off, i.e. the constituent units **30S** and **32S** are separated from each other. The other features are similar to those of the example of FIG. **14**.

FIG. **16** is a view showing a modification of the projections **30** and **32**. The projections **30** and **32** are each formed of a plurality of constituent units **30S** and **32S**. In this example, the projections **30** and **32** are bent. The other features are similar to that of FIG. **15**.

FIG. **17** is a view showing a modification of the projections **30** and **32**. The projections **30** and **32** are each configured of a plurality of constituent units **30S** and **32S**. In this case, the projections **30** and **32** are cut off, i.e. the constituent units **30S** and **32S** are separated from each other. Further, the constituent units **30S** of the projections **30** of the upper substrate **12** and the constituent units **32S** of the projections **32** of the lower substrate **14** extend in parallel to each other and are shifted from each other. The constituent units **30S** and **32S** making up the projections **30** and **32** of the upper and lower substrates, respectively, which are in contact with each other as shown in FIG. **14**, may of course be shifted as shown in FIG. **17**.

FIG. **18** is a view showing a modification of the projections **30** and **32**. The projections **30** and **32** are each configured of a plurality of constituent units **30S** and **32S**. In this case, the projections **30** and **32** are cut off, i.e. the constituent units **30S** and **32S** are separated from each other. Further, the constituent units **30S** of the projections **30** of the upper substrate **12** and the constituent units **32S** of the projections **32** of the lower substrate **14** have different lengths. The constituent unit **30S** of the projections **30** of the upper substrate **12** is about three times as long as the constituent unit **32S** of the projections **32** of the lower substrate **14**. The center of the constituent unit **30S** of the projections **30** of the upper substrate **12** coincides with the center of the three constituent units **32S** of the projections **32S** of the lower substrate **14**.

FIG. **19** is a view showing a modification of the projections **30** and **32**. The projections **30** and **32** are each formed of a plurality of constituent units **30S** and **32S**. In this example, the projections **30** and **32** are cut off, i.e. the constituent units **30S** and **32S** are separated from each other. Further, the constituent units **30S** of the projections **30** of the upper substrate **12** have different lengths, and so are the constituent units **32S** of the projections **32** of the lower substrate **14**. In this example, the constituent units **30S** and **32S** each have two types of length, and those constituent units having different lengths are formed into a set, so that sets of different lengths are arranged alternately. The set of the constituent units **30S** of the projections **30** of the upper substrate **12** and the set of the constituent units **32S** of the projections **32** of the lower substrate **14** are arranged in a staggered fashion. The constituent units **30S**, **32S** of FIGS. **18** and **19** can be arranged at a coincident position or connected as in the preceding embodiments.

FIG. **20** is a view showing a modification of the projections **30** and **32**. Each of the projections **30** and **32** is formed of a plurality of constituent units **30S**, **32S**, respectively. In this example, the constituent units **30S** of the projection **30** are arranged alternately with the constituent units **32S** of the projection **32**, and the constituent units **32S** of the projection **32** are arranged alternately with the constituent units **30S**. For example, the constituent units **30S** of the projection **30** of the upper substrate are arranged at every other position of the projection **30** of FIG. **2**, and the constituent units **32S** of the projection **32** of the lower substrate are arranged at every other position free of the constituent units **30S** of the projection **30** of the upper substrate just under the projection **30** of FIG. **2**. Apparently, the projections **30** and **32** of the upper and lower substrates appear to form each train of a mixture of constituent units **30S**, **32S** of the projections **30** and **32** of the upper and lower substrates, respectively.

In the examples described above, the constituent units **30S** and **32S** are shown in elliptical form. The present invention, however, is not limited to the elliptical shape but may be rectangular, rhombic or otherwise polygonal. Also, for the purpose of averaging the length of the constituent units **30S** and **32S** of the projections **30** and **32**, the length is preferably equal to that of the combination of the pixels of R, G and B, i.e. not more than 200 μm. Also, since the projection gap with the pair of the substrates overlapped with each other constitutes the minimum distance for controlling the alignment of the liquid crystal, the length of the constituent units **30S** and **32S** of the projections **30** and **32** is also preferably not less than the projection gap.

Although the case involving the projections **30** and **32** is described above, this is also the case with the slit structures **44** and **46** including the slits in the electrode. In other words, the slit is formed of a plurality of constituent units. In this case too, the arrangements descried above can be used as they are. This also applies to the limitation of the length of the constituent units.

FIG. **21** is a view showing a modification of the linearly arranged structures. FIG. **21** shows portions of the three

pixel electrodes **22**R, **22**G and **22**B, and the linearly arranged structures are in the zig-zag bent form, as shown in FIG. **5**. The linearly arranged structures of the upper substrate **12** includes projections **30**, and the linearly arranged structures of the lower substrate **14** includes slit structures **46**. In other words, the combination of the linearly arranged structures of FIG. **21** is equivalent to the combination of the projections and the slit structures of FIG. **7**, arranged upside down.

FIG. **22** is a view showing the pixel electrode **22**R and the slit structures **46** of FIG. **21**. The pixel electrode **22**R has a plurality of slits **22**S and a plurality of inter-slit portions **22**T of the same material (ITO) as the pixel electrode **22**R. The slits **22**S can be formed at the time of patterning the pixel electrode **22**R. The vertical alignment layer **24** is coated on the pixel electrode **22**R, so that the series of slits **22**S of the pixel electrode **22**R constitutes the slit structure **46**, and the slits **22**S make up the constituent units **46**S of the slit structure **46**. The material portions **22**T are portions where adjacent constituent units **46**S are separated.

In this embodiment, the width of the slits **22**S (the constituent unit **46**S of the slit structure **46**) is 5 μm, and the length thereof is 12 μm, 26 μm or 33 μm. The length of the slit **22**S (the constituent unit **46**S of the slit structure **46**) is preferably not less than 10 μm. The length of the material portion **22**T is 4 μm. The length of the material portion **22**T is preferably not more than the width of the projection **30**. In a similar fashion, the width of the constituent unit **30**S of the projection **30** is 5 μm, and the length thereof is 12 μm, 26 μm or 33 μm. The length of the gap between the constituent units **30**S of the projection **30** is 4 μm.

FIGS. **23**A to **23**E are views explaining the formation of the linearly arranged structures configured of the projections **30**. As shown in FIG. **23**A, a substrate **12** is prepared and a color filter, a black matrix and an electrode **18** are applied onto it. As shown in FIG. **23**B, LC 200 (made by Scibray) constituting a positive resist **50** is spin coated on the substrate **12** having the electrode **18** (not shown) for 30 seconds at 1500 rpm. The positive resist is used here but it is not necessarily used. A negative resist or a photosensitive resin other than the resist is a possible alternative. As shown in FIG. **23**C, the spin-coated resist **50** is prebaked at 90° C. for 20 minutes, and then subjected to contact exposure through a photo mask **52** (exposure time 5 seconds). As shown in FIG. **23**D, after development with the developer (by Scybray) for one minute, the resist is post-baked at 120° C. for 60 minutes followed by another post baking at 200° C. for 40 minutes thereby to form a projection **30**. The width of this projection **30** is 5 μm, the height thereof is 1.5 μm, and the length of the constituent units **30**S of the projections **30** is described above. As shown in FIG. **23**E, a vertical alignment layer JALS684 (made by JSR) is spin coated at 2000 rpm for 30 seconds, followed by baking at 180° C. for 60 minutes thereby to form the vertical alignment layer **20**.

A seal (XN-21F, made by Mitsui Toatsu Chemical) is applied to this substrate **12** or the TFT substrate **14**, and the remaining substrate is sprayed with spacers (SP-20045, made by Sekisui Fine Chemical) of 4.5 μm. The two substrates are laid one on the other. In the last step, an empty panel is produced by baking at 135° C. for 60 minutes. Rubbing and cleaning was not conducted. In vacuum environment, the empty panel is filled with the liquid crystal MJ961213 (made by Merck) having a negative anisotropy of its dielectric constant by vacuum-filling method. The insertion port is finally sealed with a sealing material (30Y@228, made by Three Bond) thereby to produce a liquid crystal panel.

The transmittance of the liquid crystal panel produced in this way was measured with the voltage of 5 V applied thereto. The measurement was 25.7%. Also, the measurement of the response speed upon application of voltages of 0 V to 5 V shows an overshoot of 1.6%.

In the case of the liquid crystal display apparatus having the linearly arranged structures of FIG. **15**, the measurement of the transmittance upon application of 5 V thereto is 26.3%. The response speed as measured upon application of voltages of 0 V to 5 V indicates the overshoot of 1.1%. The width of the projections is 10 μm, the height thereof is 1.5 μm, the length of the constituent unit of the projections is 30 μm, the distance between the projection constituent units is 10 μm, and the gap between the projections with the upper and lower substrates laid one on the other is 20 μm.

In the case of the liquid crystal display apparatus having the linearly arranged structures shown in FIG. **17**, on the other hand, the measurement of the transmittance upon application of 5 V thereto is 26.6%. The response speed as measured upon application of voltages of 0 V to 5 V indicates the overshoot of 0.9%. In the case of the liquid crystal display apparatus having the linearly arranged structures of FIG. **18**, the measurement of the transmittance upon application of 5 V is 26.1%. Also, as a measurement of the response speed taken by applying voltages of 0 V to 5 V, the overshoot is 1.6%. In this case, the width of the projection is 10 μm, the height thereof is 1.5 μm, the length of the projection constituent unit is 30 μm, the length of the other projection constituent unit is 70 μm, the gap between the projection constituent units is 10 μm and the projection gap with the upper and lower substrates laid one on the other is 20 μm. Also, a panel is produced by attaching a pair of the upper and lower substrates to each other in such a manner that each long projection constituent unit is located at the same position as two short projection constituent units.

In the case of the liquid crystal display apparatus having the linearly arranged structures shown in FIG. **20**, on the other hand, the measurement of the transmittance upon application of 5 V is 26.0%. Also, the response speed as measured upon application of 0 v to 5 V is 1.6% in terms of the overshoot. In this case, the projection has a width of 10 μm and a height of 1.5 μm, the length of the projection constituent unit is 30 μm, a gap between the projection constituent units is 50 μm, another gap between the projection constituent units is 10 μm, and the projection gap with the upper and lower substrates laid one on the other is 20 μm. Also, the projections are formed in such a manner that the projection constituent units of one substrate are located at positions corresponding to the gaps between the projection constituent units of the other substrate.

The following measurement is conducted as a comparative example 1. Projections having no constituent units are formed to produce a liquid crystal panel. The width of the projections is 10 μm, the height thereof is 1.5 μm, and the projection gap with the upper and lower substrates laid one on the other is 20 μm. The measurement of the transmittance upon application of 5 V is 22.8%. Also, the measurement of the response speed upon application of voltages of 0 V to 5 V indicates an overshoot of 7.5%.

The following measurement is taken as a comparative example 2. A liquid crystal panel having projections similar to those of FIG. **15** with longer projection constituent units is prepared. The width of the projections is 10 μm, the height thereof is 1.5 μm, the length of the projection constituent units is 300 μm, the gap between the projection constituent units is 10 μm, and the projection gap with the upper and

lower substrates laid one on the other is 20 μm. The measurement of the transmittance taken upon application of 5 V is 23.5%. Also, the measurement of the response speed upon application of 0 V to 5 V indicates the overshoot of 6.3%.

The following measurement is taken as a comparative example 3. A liquid crystal panel having projections similar to FIG. **15** with shorter constituent units is prepared. The width of the projections is 10 μm, the height thereof is 1.5 μm, the length of the projection constituent units is 10 μm, the gap between the projection constituent units is 10 μm, and the projection gap with the upper and lower substrates overlaid one on the other is 20 μm. The measurement taken of the transmittance upon application of 5 V is 24.1%. Also, the response speed as measured upon application of 0 V to 5 V indicates the overshoot of 5.9%.

FIG. **24** is a view showing the alignment of the liquid crystal of a liquid crystal display apparatus having linearly arranged structures similar to those of FIG. **11**. FIG. **25** is a view showing the display characteristic of the configuration shown in FIG. **24**. In FIG. **25**, numeral **54** designates an area which appears dark.

In FIG. **24**, the liquid crystal molecules located between the projection **30** of the upper substrate **12** and the projection **32** of the lower substrate **14** are aligned substantially perpendicular to the projections **30** and **32**. Also, the liquid crystal molecules located on the projections **30** and **32** are aligned substantially parallel to the projections **30** and **32**.

It has been found that the boundaries (singular points in director field) and the number of divisions of the areas having different alignment conditions on the projections **30** and **32** continue to change for several seconds or several tens of seconds in some cases after voltage application. It has also been found that the recognition of this phenomenon as a change in transmittance of the liquid crystal panel is a principal cause of overshoot.

This phenomenon is considered to be caused by the following fact. The liquid crystal molecules on the projections **30** and **32** are considered to be aligned either rightward or leftward in the case where the projections **30** and **32** extend horizontally, as shown in FIG. **24**, for example. In the absence of means for controlling the direction, however, the liquid crystal molecules fall randomly in one of two directions immediately after voltage application. After that, the areas of different alignment conditions on the projections **30** and **32** affect each other. Due to the absence of regulation of the directions of the alignment in these areas, however, the liquid crystal molecules easily change the status thereof under the effect from the surrounding. In this way, the liquid crystal in the areas of different orientations on the projections **30** and **32** is considered to continue to change for a long time.

As described above, the projections or slit structures configured of a plurality of constituent units has made it possible to regulated the directions of alignments by division points of constituent units.

FIG. **26** is a view showing an alignment of the liquid crystal of the liquid crystal display apparatus having linearly arranged structures including a plurality of constituent units. FIG. **27** is a view showing the display characteristic of the configuration of FIG. **26**. In FIG. **27**, numeral **54** designates an area which appears dark. FIGS. **26** and **27** indicate the features of the liquid crystal molecules of the liquid crystal display apparatus of FIG. **15**, for example.

The projections **30** and **32** are divided into areas having different alignments on the projections **30** and **32** at the cut portions **30**T and **32**T. The observation shows that the liquid crystal undergoes no secular variation at the cut portions **30**T and **32**T. It has been newly found, however, that a plurality of areas having different orientations of the liquid crystal exist also between the cut portions **30**T and **32**T and adjacent cut portions (in the constituent units **30**S and **32**S of the projections). The boundaries (singular points) between these areas have been found to undergo an age-based variation which, though minor, indicates room of further improvement of the overshoot.

FIG. **28** is a view showing the alignment of the liquid crystal of the liquid crystal display apparatus having the linearly arranged structures according to the second embodiment of the present invention. FIG. **29** is a view showing the display characteristic of the configuration shown in FIG. **28**. FIG. **30** is a view showing, in enlarged form, the features of the boundaries (singular points) of alignment of first type and the features of the boundaries (singular points) of alignment of second type indicated in FIG. **28**.

In FIGS. **28** and **30**, a study of the means capable of controlling the alignment of the liquid crystal on the projections **30** and **32** shows that there are two types of boundaries (singular points in director field), regarding boundaries of a plurality of areas having different liquid crystal alignment conditions. In the first type (I), the liquid crystal molecules around a point are directed toward said point. In the second type (II), some of the liquid crystal molecules around a point are directed to said point while the remaining ones are directed opposite to the same one point. In FIG. **28**, the liquid crystal molecules are each shown to have a head and a leg. In the first type (I), all the heads or all the legs of all the liquid crystal molecules are directed to the center. In the second type (II), on the other hand, some liquid crystal molecules have the heads thereof directed to the center while the remaining liquid crystal molecules have the legs thereof directed to the center.

In FIG. **28**, the projections **30** and **32** constituting the linearly arranged structures of each substrate include means **56** for forming boundaries of alignment of first type (I) in which the liquid crystal molecules surrounding a point are directed toward said point, and means **58** for forming the boundaries of alignment of second type (II) in which a part of the liquid crystal molecules surrounding a point are directed toward said point and the remaining liquid crystal molecules are directed away from the same one point. The means **56** for forming the boundaries of alignment of first type (I) are arranged in the constituent units **30**S and **32**S of the projections **30** and **32**, while the means **58** for forming the boundaries of alignment of second type are arranged in the boundaries between the constituent units **30**S and **32**S of the projections **30** and **32** (i.e. in the separation sections **30**T and **32**T for separating the constituent units **30**S and **32**S).

As seen from the foregoing description and FIG. **2**, the projections **30** and **32** can control the alignment of the liquid crystal molecules by means of the main slopes thereof. In a similar fashion, the separation sections **30**T and **32**T defining the boundaries (singular points in director field) between the constituent units **30**S and **32**S of the projections **30** and **32** also have slopes with which the alignment of the liquid crystal molecules can be controlled. The slopes of the separation sections **30**T and **32**T generally extend transversely to the length of projections **30** and **32**. The main slopes of the projections **30** and **32** have the function to align the liquid crystal molecules perpendicular to the length of the projections **30** and **32**. The slopes of the separation sections **30**T and **32**T, in contrast, are adapted to align the liquid crystal molecules substantially parallel to the length

of the projections **30** and **32**. On the other hand, the liquid crystal molecules are generally aligned perpendicular to the length of the projections **30** and **32**, and the function is similar for the separation sections **30**T and **32**T. Thus, the separation sections **30**T and **32**T constitute means **58** for forming the boundary of second type (II).

FIGS. **31** and **32** show specific examples of the means **56** for-forming the boundaries of alignment of first type (I). FIG. **32** is a cross-sectional view of both the cross-section passing through the projection **30** of the upper substrate **12** and of the cross-section passing through the projection **32** of the lower substrate **14**. The means **56** includes dot-like projections formed on the projections **30** and **32**, respectively. The means **56** aids the alignment of the liquid crystal in terms of shape or electric field and thus can align the liquid crystal molecules in the manner described above. With this portion as a nucleus, the alignment areas of the liquid crystal on the projections **30** and **32** can be divided. The liquid crystal is differently aligned in the boundary of first type (I) and the boundary of second type (II), and therefore the projections have naturally different effects on them.

The means **56** for forming the boundaries of alignment of a first type (I) can cause the liquid crystal molecules to lie toward the higher position on the projections on the upper substrate **12**. Only after the cut portions and the heights of the projection are arranged alternately in this way, can the directions of alignments of all the domains on the projection be determined. Thus, the age-based variation of the domains of the liquid crystal after voltage application can be suppressed, and the overshoot can be eliminated substantially in its entirety.

In order to form the means **56** projecting on the projections **30** and **32**, small structures are formed before forming the projections **30** and **32**. The small structures may alternatively be formed after forming the projections **30** and **32**. The small structure has a size of 10 μm square and a height of 1 μm. The small structures are made of the same material as the projections in the case under consideration. For forming the small structures on the TFT substrate, a method is available in which a wiring metal layer or an dielectric layer is deposited at the particular portion. For the CF substrate, on the other hand, the desired structure can be obtained without increasing the number of processes by depositing a color layer or a BM at the particular portion.

A photosensitive acrylic material PC-335 (made by JSR) is used for the projections. The projections have the width of 10 μm, the projection gap (the distance from the projection end of one substrate to the projection end of the other substrate after the substrates are attached to each other) is 30 μm, and the projection height is 1.5 μm (the height of the projection which is originally 1 μm higher is 2.5 μm tall). The separated sections **30**S and **32**S of the projections **30** and **32** have the size of 10 μm square, and the distance from the center of the separated sections **30**S and **32**S to the center of the height **56** of the projections **30** and **32** is 60 μm (the projection 1.5 μm tall exists continuously for the length of 50 μm).

The vertical alignment layer is made of JALS-204 (made by JSR). Microbar (made by Sekisui Fine Chemical) 3.5 μm in diameter is used as a spacer mixed with the liquid crystal, and MJ95785 (made by Merk) as a liquid crystal material.

FIGS. **33** and **34** are a plan view and a cross-sectional view, respectively, showing a modification of the linearly arranged structures. This example is similar to the preceding one except for the following points. Specifically, the upper and lower substrates **12** and **14** have projections **30** and **32**, respectively, and the tall portions and the low portions are alternately formed in the projections **30** and **32** as the means **56** for forming the boundaries of alignment of first type (I) and the means **58** for forming the boundaries of alignment of second type (II). The low portions **58** of the projections **30** and **32** are the separation sections **30**T and **32**T for separating the constituent units **30**S and **32**S. The low portions have the projection height of 1 μm. As a method of reducing the height of the projection, according to this embodiment, the projections **30** and **32** formed in this embodiment are selectively ashed by radiation from an oxygen plasma. Also, in the case where the projections are formed on the TFT substrate, the desired structure can be obtained by a method for opening contact holes in the particular portion. For a CF substrate, on the other hand, a method for removing the color layer and the overcoat layer of the particular portion can be used without increasing the processes.

FIG. **35**A is a plan view showing a modification of the linearly arranged structures. The upper and lower substrates **12** and **14** have projections **30** and **32**. The projections **30** and **32** have alternately wide portions and narrow portions as the means **56** for forming the boundaries of alignment of first type (I) and the means **58** for forming the boundaries of alignment of second type (II). The width of the wide portion **56** is 15 μm, and the width of the narrow portion **58** is 5 μm (normally, the width is 10 μm).

FIG. **35**B is a plan view showing a modification of the linearly arranged structures. The upper and lower substrates **12** and **14** have projections **30** and **32**. A wide portion and a narrow portion of the projections **30** and **32** are alternately arranged as the means **56** for forming the boundaries of alignment of first type (I), and the means **58** for forming the boundaries of alignment of second type (II).

FIG. **36** is a plan view showing a modification of the linearly arranged structures. The lower substrate **14** has slits **46** as the linearly arranged structures. The width of the slit **46***s* is continuously changed and wide portions are alternated with narrow portions, as the means **56** for forming the boundaries of alignment of first type (I) and the means **58** for forming the boundaries of alignment of second type (II).

FIG. **37** is a plan view showing a modification of the linearly arranged structures. The upper substrate **12** is a CF substrate, and the lower substrate **14** is a TFT substrate. The panel size is 15 inch type, and the, number of pixels is 1024×768 (XGA). FIG. **37** shows one pixel unit of the panel. The height of the central portions **32**P of the projections **32** of the TFT substrate **14** is reduced, and the height of the central portions **30**P of the projections **30** of the CF substrate **12** is increased. Taking the effect of the edge of the pixel electrodes **22** into account, the desired alignment could be realized.

In an application of the present invention to a liquid crystal panel using a TFT substrate, it is necessary to take into full consideration the effect of the edge of the pixel electrodes **22** of the TFT substrate on the direction of the electric field.

FIGS. **38**A and **38**B are partial cross-sectional views showing the neighborhood of the edge of the pixel electrode **22** of the liquid crystal display apparatus, and FIGS. **39**A and **39**B are views showing the alignment of the liquid crystal at the edge of the pixel electrode **22** of FIGS. **38**A and **38**B. FIGS. **38**A and **39**A show a portion of the projection **30** of the upper substrate **12**, and FIGS. **38**B and **39**B a portion of the projection **32** of the lower substrate **14**. As shown in

FIGS. **38**A to **39**B, an oblique electric field **60** exists at the edge of the pixel electrode **22**. This oblique electric field **60** plays the role of directing the liquid crystal molecules toward the center of the pixel, when viewed, so that the TFT substrate is arranged below the CF substrate. This indicates that the edge of the pixel electrode **22** has the same function as the means **56** for forming the boundary of orientation of first type (I) on the projection **32** of the TFT substrate, and has the same function as the means **58** for forming the boundaries of second type (II) against the projection **30** of the CF substrate.

In other words, the boundary nearest to the edge of the pixel electrode on the projection **32** of the TFT substrate always assumes the status of alignment of second type (II) and the boundary nearest to the edge of the pixel electrode always assumes the status of first type (I) on the projection **30** of the CF substrate. As a result, the configuration of FIG. **37** permits the alignment control of all the domains on the projection for the TFT liquid crystal panel by determining the direction of alignment on the projections **30** and **32** in accordance with the direction of regulation by the edge of the pixel electrode.

FIG. **40** is a plan view showing a modification of the linearly arranged structures. For the TFT substrate, the projection height is reduced as the alignment control means **58** on the projection **32** nearest to the edge of the pixel electrode, while the projection height is increased as the alignment forming means **56** inside. For the CF substrate, on the other hand, the projection height is increased as the alignment control means **56** on the portion of the projection **30** nearest to the pixel edge, while the projection height is reduced as the alignment forming means **58** inside.

In the embodiments described above, the dot-projections are formed in the same manner for the upper and lower substrates, but it is not necessary to do so. For example, the upper substrate may be formed with higher dot-projections and lower dot-projections, while the lower substrate may be formed with wider dot-projection and narrower dot-projections with equal effect. Also, only the two types of shapes need not be alternated on the same projections.

For example, the repetition of higher and lower dot-projections is not always necessary, but an alternative is to arrange a higher dot-projection, a lower dot-projection, a wider dot-projection, a narrower dot-projection, a higher dot-projection and a lower dot-projection in that order, for example. Anyway, the only requirement is to alternate the shape change satisfying the conditions for the boundaries of first and second types (I) and (II). This shape change for the projections and the slits is shown in Table 1.

TABLE 1

Boundary forming means 56 of first type (I)
Increase projection height
Increase projection width
Remove electrode under projection
Increase slit height (protrude)
Increase slit width
Boundary forming means 58 of second type (II)
Cut projection
Reduce projection height
Reduce projection width
Cut slit
Reduce slit height (form a hole)
Reduce slit width

FIG. **41** is a view showing the alignment of the liquid crystal on the linearly arranged structures of FIG. **35**. In this case, the alignment in the display domain is the bend form.

FIG. **42** is a view showing a modification of the linearly arranged structure of FIG. **41**. In this case, the alignment of the display domain is the spray form. By changing from the configuration of FIG. **41** to the configuration of FIG. **42**, the bend alignment can be changed to the spray alignment.

FIG. **43** is a plan view showing the alignment control structures according to the third embodiment of the present invention. FIG. **44** is a cross-sectional view passing through the alignment control structures of FIG. **43**. The basic configuration of this liquid crystal display apparatus is similar to that of the liquid crystal display apparatus according to the embodiment shown in FIGS. **1** to **5**. Specifically, the liquid crystal display apparatus **10** includes projections **30** and **32** as the alignment control structures (linearly arranged alignment control structures) for controlling the alignment of the liquid crystal between the projections **30** and **32** (display domain). The projections **30** and **32** are arranged in the direction parallel to each other and displaced from each other, as viewed normal to the substrate. FIG. **44** is a cross-sectional view passing through the projection **32** of the lower substrate **14** and the projection **30** of the upper substrate **12** is not shown in FIG. **44**.

In this embodiment, the upper substrate **12** and the lower substrate **14** include means **62** and **64**, respectively, for forming the boundary of alignment of the liquid crystal molecules (singular points in director field) at fixed positions on the opposed substrate upon application of a voltage thereto. In FIG. **44**, the upper substrate **12** includes means **62** having a dot-projection **62***a* in the same cross-section as the projection **32** of the lower substrate **14**. In a similar fashion, as shown in FIG. **43**, the lower substrate **14** includes means **64** having a dot-projection **64***a* in the same cross-section as the projection **30** of the upper substrate **12**.

FIG. **45** is a view showing the alignment of the liquid crystal in the neighborhood of the linearly arranged structure of FIG. **44**. FIG. **46** is a view showing the alignment of the liquid crystal in the neighborhood of the linearly arranged structure according to the first embodiment.

In the first embodiment, the projections **30** and **32** are each formed of a plurality of constituent units **30**S and **32**S. The means **62** and **64** for forming the boundary of alignment of the liquid crystal molecules at a predetermined position according to this embodiment have the same function as the projections **30** and **32** formed of a plurality of constituent units **30**S and **32**S in the first embodiment. As seen from the comparison between FIGS. **45** and **46**, the positions where the means **62** and **64** are formed along the projections **30** and **32** of the means **62** and **64** are the same as the cut portions or the boundaries of a plurality of constituent units **30**S and **32**S in the first embodiment.

As shown in FIGS. **44** and **45**, the means **62** is intended to cause the liquid crystal molecules on the projection **32** to fall toward the dot-projection **62***a* of the means **62**. In similar fashion, the means **64** is adapted to cause the liquid crystal molecules on the projection **30** to lie toward the projection **64***a* of the means **64**. Thus it is seen that the means **62** and **64** have the same significance as the projections **30** and **32** formed of a plurality of constituent units **30**S and **32**S whereby the liquid crystal molecules tend to lie toward the cut portions or the boundaries **32**T.

In the configuration of FIG. **46**, the liquid crystal molecules located on the side of the projection **32** are desirably aligned perpendicular to the projection **32**. The liquid crystal molecules on the side of the cut portions or the boundaries **32**T where the projection **32** is discontinuous, however, are not necessarily turned perpendicular to the projection **32**. In

the configuration of FIGS. **44** and **45**, the projection **32** is not discontinuous, and therefore the liquid crystal molecules located on the side of the projection **32** are all positioned perpendicular to the projection **32**. Thus, the alignment of the liquid crystal in both the display area and the area on the projection can be controlled without reducing the brightness.

The dot-projections **62**a and **64**a are made of the photosensitive acrylic material PC-335 (made by JSR). The dot-projections **62**a and **64**a have the width of 5 μm and the height of 1.5 μm. The width of the linear projections **30** and **32** is 10 μm and the height thereof is 1.5 μm.

FIGS. **47**A to **47**C are views showing a modification of the linearly arranged structure and the control means for the boundary alignment. FIG. **47**A is a cross-sectional view, FIG. **47**B an illustrative perspective view, and FIG. **47**C is a plan view. In this embodiment, the means **62** for forming the boundary of alignment of the liquid crystal molecules at a predetermined position is a dot-slit structure **62**b on the opposed substrate. The means **62** is arranged by forming a slit in the electrode **18** and forming the vertical alignment layer **20** on the electrode **18**. The size of the slit is 14×4 μm or 10×4 μm at which the display brightness is improved. The slit width can be further reduced.

FIG. **48** is a view showing a modification of the control means for alignment in the boundaries and the linearly arranged structures. In this embodiment, the means **62** for forming the boundary of alignment of the liquid crystal molecules at a predetermined position is the dot-projection **62**a. The dot-projection **62**a is produced in such a manner that a slit or a hole is formed in the electrode **18**, a projection **66** is formed on the substrate in the slit or hole, and then the vertical alignment layer **20** is formed on the electrode **18**. The width of the dot-projection **62**a is 3 μm, the length 8 μm, and the height 1.5 μm. The projection **66** is formed of an acrylic resin. As projection forming means, the material of the bus line or the dielectric layer can be selectively used for the TFT substrate. For the CF substrate, on the other hand, the material of a color filter layer, a black mask layer or an overcoat layer can be selectively used.

Also, in place of providing the projection **66**, a slit or a hole may be formed as a depression in the substrate, so that means **62** for forming the boundary of alignment of the liquid crystal molecules at a predetermined position can be a slit structure. For the TFT substrate, on the other hand, a contact hole can be selectively formed as a depression. In the case of the CF substrate, on the other hand, a depression can be formed selectively in the color filter layer, the black mask layer or the overcoat layer.

FIG. **49** is a view showing a modification of the control means for the boundary of alignment and the linearly arranged structures. According to this embodiment, the means **62** for forming the boundary of alignment of the liquid crystal molecules at a predetermined position is a dot-projection **62**a. The means **62** is such that a projection **68** is formed on the substrate **12**, an electrode **18** is formed, and then a vertical alignment layer **20** is formed. The means **62** can also be formed of a slit structure by forming a depression in the substrate **12**.

FIG. **50** is a view showing a modification of the control means for the boundary of alignment and the linearly arranged structures. In FIGS. **43** to **49**, the linearly arranged structures are configured of the projections **30** and **32**. As an alternative, the linearly arranged structures can be formed of the slit structures **44** and **46** (FIGS. **7** and **8**). In this embodiment, the linearly arranged structures are formed of the slit structures **46**, and the means **62** for forming the boundary of alignment of the liquid crystal molecules at a predetermined position is configured of the dot-projection **62**a. The means **62** is such that the projection **68** is formed on the substrate **12**, the electrode **18** is formed and then the vertical alignment layer **20** is formed.

FIG. **51** is a view showing a modification of the control means for boundary of alignment and the linearly arranged structures. In FIGS. **52** and **53** are cross-sectional views. In this case, the projections **30** and **32** are provides in a bent form, as the linearly arranged structures. As described above, it is necessary to take into account the effect of the oblique electric field from the edge of the pixel electrode **22** of the TFT substrate onto the opposed electrode **18**. In this case, among the wedge-shaped declinations formed on the projection **32** of the TFT substrate, the disclination nearest to the edge of the pixel electrode has the intensity s=−1, which corresponds to the boundary of second type (II) in FIG. **28**. Among the wedge-type declinations formed on the projection of the CF substrate, on the other hand, the declination nearest to the edge of the pixel electrode has the intensity s=+1, which corresponds to the boundary of first type (I) of FIG. **28**. In an application to an actual liquid crystal panel, the direction of alignment on the projections **30** and **32** is determined in accordance with the formation of the disclination by the edge of the pixel electrode **22**, thereby making it possible to control all the domains in the pixel in a stable fashion.

In this embodiment, the electrode located at the portion, in opposed relation to the projection **30** of the CF substrate, is selectively protruded to constitute the means **64** for forming the boundary of alignment of the liquid crystal molecules at a predetermined position. Also, the portion in opposed relation to the projection **32** of the TFT substrate is selectively formed with a projection, thereby constituting the means **62** for forming the boundary of alignment of the liquid crystal molecules at a predetermined position. Further, in the case where a plurality of wedge-shaped declinations are arranged on one projection in the pixel, the alignment control means is provided to arrange the disclinations of s=−1 and s=+1 alternately. According to this embodiment, as shown in FIG. **53**, the means **62** with the electrode **22** protruded above the projection **68** and the means **62** with the projection **69** protruded above the electrode **22** are arranged alternately with each other.

FIGS. **54** and **55** are views showing a modification of the control means for the boundary of alignment and the linearly arranged structures. In this embodiment, the means **62** for forming the boundary of alignment of the liquid crystal molecules at a predetermined position is formed as a slit **71** in the projection **70** extending long on the upper substrate **12** in opposed relation to the projection **32** of the lower substrate. The projection **70** is arranged on the electrode **18** and narrower than the projection **32**.

FIGS. **56** and **57** are views showing a modification of the control means for orientation the boundary of alignment and the linearly arranged structures. In this embodiment, the means **62** for forming the boundary of alignment of the liquid crystal molecules at a predetermined position is formed as a slit **71** in the projection **70** extending long on the upper substrate **12** in opposed relation to the projection **32** of the lower substrate and a slit **72** of the electrode **18**. The projection **70** is arranged on the electrode **18** and narrower than the projection **32**.

FIGS. **135**A to **157**D are views showing examples of auxiliary structures for forming the disclinations of s=+1 and s=−1, where one of the substrate has the alignment control

structures and the other substrate has the auxiliary structures at positions opposite to the alignment control structures. The alignment control structures of the substrate can be projections or slits.

Examples of means for realizing s=−1 are shown in FIGS. **135**A to **147**B, and summarized as follows: Dot-projection (FIGS. **135**A and **135**B); Dot-cut out in electrode (FIGS. **136**A and **136**B); Dot-recess in electrode (FIGS. **137**A and **137**B); Narrow linear projection and partial cut out in electrode under the narrow projection (FIGS. **138**A to **138**E); Narrow linear projection and partial enlarged portion on the narrow projection (FIGS. **139**A and **139**B); Narrow linear projection and partial higher portion on the narrow projection (FIGS. **140**A and **140**B); Narrow linear electrode projection and partial lower portion on the narrow electrode projection (FIGS. **141**A to **141**D); Narrow linear electrode projection and partial cut out in the electrode (FIGS. **142**A to **142**D); Narrow linear electrode projection and partial narrow portion (FIGS. **143**A to **143**D); Narrow linear electrode projection and partial lower portion (FIGS. **144**A and **144**B); Narrow linear electrode recess and partial lower portion (FIGS. **145**A and **145**B); and Narrow linear electrode recess and partial enlarged portion (FIGS. **146**A to **146**D).

Examples of means for realizing s=+1 are as follows, as shown in FIGS. **147**A to **157**D. Dot-projection of electrode (FIGS. **147**A and **147**B); Narrow linear projection and partial separation (FIGS. **148**A and **148**B); Narrow linear projection and partial narrow portion (FIGS. **149**A and **149**B); Narrow linear projection and partial lower portion (FIGS. **150**A and **150**B); Narrow linear slit and partial connection (FIGS. **151**A and **151**B); Narrow linear slit and partial narrow portion (FIGS. **152**A to **152**D); Narrow linear slit and partial lower portion (FIGS. **153**A to **153**D); Narrow linear electrode projection and partial enlarged portion (FIGS. **154**A to **154**D); Narrow linear electrode projection and partial higher portion (FIGS. **155**A and **155**B); Narrow linear electrode recess and partial higher portion (FIGS. **156**A and **156**B); and Narrow linear electrode recess and partial narrow portion (FIGS. **157**A to **157**D).

FIG. **58** is a plan view showing the linearly arranged structures according to the fourth embodiment of the present invention. FIG. **59** is a cross-sectional view of the liquid crystal display apparatus taken along the line **59**—**59** in FIG. **58**. The basic configuration of this liquid crystal display apparatus **10** is similar to the basic configuration of the liquid crystal display apparatus **0.10** according to the embodiments shown in FIG. **1** to **5**. In this embodiment, the projections (alignment control structures) **30** and **32** are each formed of a plurality of constituent units **30***a* and **32***a*, respectively. As viewed from the direction normal to one substrate, the constituent units of the linearly arranged structure of the one substrate and the constituent units of the linearly arranged structure of the other substrate are arranged alternately on one line.

Taking the constituent units of the projection on the upper line (line **59**—**59**) in FIG. **58**, as examples, the constituent units **30***a* of the projection **30** on the upper substrate **12** and the constituent units **32***a* of the projection **32** of the lower substrate **14** are alternately arranged on the particular line. FIG. **59** shows the constituent units **30***a* and **32***a*. As shown in FIG. **59**, the liquid crystal molecules located on this line fall continuously in the direction parallel to the line. As explained with reference to FIG. **11**, therefore, the problem that the liquid crystal molecules on the projection fall in random directions can be solved.

Noting the left half portion in FIG. **58**, the relative positions of the constituent units **32***a* of the projection **32** of the lower substrate **14** on the upper line, the constituent units **30***a* of the projection **30** of the upper substrate **12** on the intermediate line, and the constituent units **32***a* of the projection **32** of the lower substrate **14** on the lower line, are the same as the arrangement of FIGS. **3** and **4**. The relative positions are the same as in the case where these projections are in opposed relationship in a plane at an angle to the substrate surface as shown in FIG. **2**. This is also the case with FIG. **58**. Thus, the operation of this liquid crystal display apparatus is basically the same as the operation of the first embodiment. Especially, with this configuration, the response speed for a half tone can be improved. By the way, the configuration of FIG. **58** is similar to that of FIG. **20**.

FIGS. **60** and **61** are diagrams views a modification of the linearly arranged structures. In this case, the projection **30** is used as a linearly arranged structure of the upper substrate **12**, while the slit structure **46** is used as a linearly arranged structure of the lower substrate **14**. The slit structure **46** can be divided into the constituent units **46***a* as shown in FIG. **61**. In this case, the electrical connection of the individual pixel electrodes separated by the slits can be realized with a larger width thereby leading to the advantage of a wider design margin. Another advantage is that there is no likelihood of disconnection or resistance increase in the connector between the slits of the pixel electrode **22**.

In this example, each linearly arranged structure has a plurality of constituent units in one pixel and a linear wall structure is arranged substantially symmetrically in one pixel. A similar feature is obtained also in the application to the bent linearly arranged structures shown in FIG. **21**.

FIG. **62** is a view showing a modification of the linearly arranged structure. In this case, the constituent units **30***a* and **32***a* of the projections **30**, **32** are arranged alternately as in the case shown in FIG. **58**, and at the same time, means **74** is provided for forming the boundary of alignment in such a manner that at least one of the constituent units **30***a* and **32***a* of the projections **30** and **32** has the liquid crystal molecules around a point directed toward said point. The means **74** for forming the boundary of alignment is analogous, for example, to the means **56** for forming the boundary of alignment of first type (I) shown in FIG. **28**. The alignment of first type (I) forms a singularity point of the alignment vector corresponding to s=1. In this case, the alignment vector of the minor domains on the projection can be controlled, with the result that the stable control of the display domains is realized for an improved response speed for a half tone.

The means **74** can be similar to the corresponding one of the second embodiment described above.

FIG. **63** shows a specific example of the means **74** for forming the boundary of alignment. In FIG. **63**, the means **74** is to enlarge the width of the constituent units **30***a* and **32***a* of the projections **30** and **32**.

Also, as shown in FIG. **64**, the means **74** can also be achieved by increasing the height of the constituent units **30***a* and **32***a* of the projections **30** and **32**.

At a point where the width of the constituent units **30***a* and **32***a* of the projection is partially increased or the height is increased, the liquid crystal director widens from the particular part as a center and therefore the particular point constitutes a singularity point of s=1. Also, in the case where the common substrate is arranged on this side, the liquid crystal director toward the center of the pixel from the edge of the pixel electrode rises toward the center on all the projections due to the oblique electric field of the pixel electrode. Thus, it is possible to form a minor domain which is continuously connected smoothly in the projection boundary.

FIG. **65** shows a specific example of the means **74** for forming the boundary of alignment. In FIG. **65**, the linearly arranged structures are combination of the projections **32** and the slit structures **44**. The means **74** can be achieved by increasing the width or height of the constituent units **32***a* of the projection **32** and by increasing the width or depth of the slit structure **44**.

The response speed as compared with the corresponding speed in the structures of the first embodiment is shown in Table 2 (slit width 10 μm, projection width 10 μm and distance 20 μm between projections).

TABLE 2

	1st embodiment	4th embodiment	Drive condition
$T_{ON} + T_{OFF}$	25 ms	−25 ms	0 to 5 V
$T_{ON} + T_{OFF}$	50 ms	−40 ms	0 to 3 V

In this way, the response speed can be improved by the smooth motion of the minor domains on the projections. Thus, the improvement of the response for a half tone with a stable orientation can be assured. Also, the width of the electrical connector of the slits can be increased, leading to the advantage that there is no fear of disconnection.

This embodiment was explained with reference to two divisions as an example. The same can be applied to the bent type linearly arranged structures. Also, several embodiments can be combined.

FIG. **66** is a plan view showing the linearly arranged structures according to the fifth embodiment of the present invention. The basic configuration of this liquid crystal display apparatus **10** is similar to that of the liquid crystal display apparatus **10** according to the embodiments of FIGS. **1**, **2** and **5**. In the embodiment of FIG. **5**, the projections (linearly arranged structure) **30** and **32** extend parallel to each other and are bent. With this configuration, one pixel includes four areas of alignment of the liquid crystal molecules **16**C, **16**D, **16**E and **16**F, oriented in thereby making possible the alignment division with a superior visual angle characteristic.

The two line segments forming the bent portion of the projections **30** and **32** are at an angle of 90 degrees. The polarizers **26** and **28** are arranged in such a manner that the polarization axes form an angle of 45 degrees to the line segments of the bent portion of the projections **30** and **32**, as designated by **48**. Although only a part of the liquid crystal molecules is shown in FIG. **66**, there are four areas of alignment of the liquid crystal molecules **16**C, **16**D, **16**E and **16**F (FIG. **5**) in one pixel.

In this embodiment, additional projections **76** and **78** constituting additional linear wall structures are arranged on the obtuse angle side of the bent portions of the substrates having the projections **30** and **32**. Specifically, the additional projection **76** is arranged continuously from the projection **30** on the obtuse angle side of the projection **30** of the upper substrate **12**. The additional projection **76** extends along the bisector of the obtuse angle on the obtuse angle side of the projection **30** of the upper substrate **12**. On the other hand, the additional projection **78** is arranged continuously from the projection **32** on the obtuse angle side of the projection **32** of the lower substrate **14**. The additional projection **78** extends along the bisector of the obtuse angle on the particular obtuse angle side of the projection **32** of the lower substrate **14**. As a result, the brightness is improved for a higher response.

FIG. **67** shows projections **30** and **32** similar to the corresponding ones in FIG. **5**. FIG. **67** shows in more detail the alignment of the liquid crystal molecules with respect to the projections **30** and **32**. One pixel contains four areas of alignment of the liquid crystal molecules **16**C, **16**D, **16**E and **16**F. Further, there is an area of liquid crystal molecules **16**G on the obtuse angle side of the bent portion of the projection **30**, and liquid crystal molecules **16**H on the obtuse angle side of the bent portion of the projection **32**. At the time of voltage application, the liquid crystal molecules should lie in the direction perpendicular to the projections **30** and **32**, respectively. At the bent portions of the projections **30** and **32**, however, the liquid crystal molecules are aligned in such a manner that the liquid crystal molecules **16**G and **16**H are aligned in parallel along the bisector of the obtuse angle of the bent portions of the projections **30** and **32** since the liquid crystal molecules **16**D–**16**F and **16**C–**16**E located on the two line segments forming the bent portions are aligned continuously. The direction of alignment of the liquid crystal molecules **16**G and **16**H is parallel or perpendicular to the polarization axes indicated by **48**, and in the case where a white display is formed by applying a voltage, the areas of the liquid crystal molecules **16**G and **16**H become dark.

FIG. **68** shows a screen when a white display is viewed on the liquid crystal display apparatus having the linearly arranged structures of FIG. **67**. The areas G and H of the liquid crystal molecules **16**G and **16**H actually darken. Also, the areas I at the edges of the pixel electrodes **22** darken. This will be explained later.

In FIG. **66**, the additional projections **76** and **78** are formed on the obtuse angle side of the bent portions of the substrates having the projections **30** and **32**, and therefore, the alignment of the liquid crystal molecules **16**G and **16**H in question is corrected to realize almost the same alignment as the liquid crystal molecules **16**D–**16**F and **16**C–**16**E located on both sides thereof. As a result, the areas G and H shown in FIG. **68** are not darkened and the brightness is improved.

The width of the additional projections **76** and **78** can be the same as the width of the original projections **30** and **32**. Nevertheless, the width of the additional projections **76** and **78** is desirably smaller than the width of the original projections **30** and **32**. This is by reason of the fact that, if the additional projections **76** and **78** have a strong power for controlling the alignment, the neighboring liquid crystal molecules come to be aligned perpendicular to the additional projections **76** and **78**. If the additional projections have only a small power for controlling the alignment, on the other hand, the neighboring liquid crystal molecules are not aligned perpendicular to the additional projections **76** and **78** but assume the almost the same alignment as the liquid crystal molecules **16**D–**16**F and **16**C–**16**E located on both sides thereof. In the case where the width of the original projections **30** and **32** is 10 μm, for example, the desirable width of the additional projections **76** and **78** may be about 5 μm.

By forming the additional projections **76** and **78** on the projections **30** and **32** as described above, the manner in which the liquid crystal molecules at the bent portion fall can be definitely determined, and therefore both the brightness and the response can be improved.

In this embodiment, the glass substrates **12** and **14** are made of NA-35 in the thickness of 0.7 mm. The pixel electrodes **22** and the common electrode **18** are made of ITO. TFTs for driving the liquid crystal and bus lines are arranged on the substrate having the pixel electrodes **22**, while a color filter is arranged on the opposed substrate having the common electrode **18**. The photosensitive acrylic material

PC-335 (made by JSR) is used for the projections. For both the substrates, the projection width is 10 μm and the projection interval (the distance from the projection end of one substrate to the projection end of the other substrate after attaching the two substrates to each other) is 30 μm. The projection height is 1.5 μm. The vertical alignment layers **20**, **24** are made of JALS-204 (made by JSR). The liquid crystal material of MJ95785 (made by Merc) is used. The spacer is Microbar having a diameter of 3.5 μm (made by Sekisui Fine Chemical).

FIG. **69** shows a modification of the linearly arranged structures. In this example, additional projections **76*x*** and **78*x*** are arranged on the acute angle side of the bent portions of the projections **30** and **32**. In this case, alignment of the liquid crystal molecules controlled by the projections **30**, **32** is not smoothly connected to alignment of the liquid crystal molecules controlled by the additional projections **76*x*** and **78*x***. Thus, the liquid crystal molecules in the neighborhood of the bent portions of the projections **30** and **32** are aligned in the direction at right angles or perpendicular to the direction of the polarization axes, resulting in an insufficient improvement. It has been found, therefore, that the additional projections **76*x*** and **78*x*** are preferably arranged on the obtuse angle side of the bent portions of the projections **30** and **32**, as shown in FIG. **66**.

The additional projections **76** and **78** have thus far been explained as viewed from the same substrate as the one having the projections **30** and **32**. When viewed from the substrate opposed to the one formed with the projections **30** and **32**, the additional projections **76** and **78** assume the following form. In FIG. **66**, for example, the additional projection **76** is formed on the acute angle side of the bent portion of the projection **32** of the substrate **14** in opposed relationship to the substrate **12** having the projections **30**. In a similar fashion, the additional projection **78** is formed on the acute angle side of the bent portion of the projection **30** of the substrate **12** in opposed relationship to the substrate **14** having the projections **32**.

FIG. **70** shows a modification of the linearly arranged structures. In this example, as in the example of FIG. **66**, the additional projections **76** and **78** are formed on the obtuse angle side of the bent portions of the projections **30** and **32**. The projections **76** and **78** in this example extend further than the projections **76** and **78** of FIG. **66**. The forward end of each of the additional projections **76** and **78** extends to a point where it is overlapped with the bent portions of the projections **32** and **30** in opposed relationship thereto. The additional projections **76** and **78** may be extended in this way but are not desirably extended beyond the point where the forward end thereof is overlapped with the bent portions of the projections **32** and **30**.

Further, in this example, the upper substrate **12** and the lower substrate formed with the projections **32** and **30** and the additional projections **76** and **78** are attached to each other with the peripheral portions thereof sealed. Thus, an empty panel is formed, into which the liquid crystal is injected subsequently. In this example, the height of the projections is 1.75 μm, and the projections of the substrates partially contact with each other, so that the cell thickness of 3.5 μm is secured. The cell thickness can be maintained by partial contact between the projections of the two substrates, without using spacers. If a spacer is inserted, the orientation of the liquid crystal molecules would be affected also on the surface of the spacer. In this arrangement, there is no spacer, and any abnormal alignment which otherwise might be caused by spacers is eliminated.

As described above, the linearly arranged structures for controlling the alignment is configured of the projections **30** and **32** or the slit structures **44** and **46**. In the case where the slit structures **44** and **46** are employed as linearly arranged structures, additional slit structures similar to the slit structures **44** and **46** are provided in place of the additional projections **76** and **78**. Also, the linearly arranged structures for controlling the alignment may be configured of projections on slits which are formed in the electrode.

FIG. **71** shows a modification of the linearly arranged structures. As the linearly arranged structures for controlling the alignment, the projections **30** of the upper substrate **12** and the slit structures **46** of the lower substrate **14** are provided. As described above, the slit structures **46** are configured by forming slits in the pixel electrodes **22** of the lower substrate **14**. The additional projection **76** is provided in a similar manner to the additional projection **76** of FIG. **66**, and the additional slit structure **78*y*** is provided on the obtuse angle side of the bent portion of the slit structure **46** in place of the additional projection **78** of FIG. **66**. The additional slit structure **78*y*** is not connected to the bent portion of the slit structure **46** by reason of the fact that the slit has a discontinuous portion as the slit structure **46** is configured as a slit in the pixel electrode **22**. By the way, the additional slit structure **78*y*** can be said to be provided on the acute angle side of the projection **30** of the opposed substrate.

FIG. **72** shows a modification of the linearly arranged structures. In this example, as in the case of FIG. **66**, the additional projections **76** and **78** are provided. Further, the edge projections **80** are provided at points where they are overlapped with at least a part of the edge of the pixel electrode **22**. In such a case, the projections **30** and **32** are arranged neither in parallel nor perpendicular to the edge of the pixel electrode **22**. The edge projections **80** are arranged at positions corresponding to the areas I of FIG. **68**. As shown in FIG. **67**, the liquid crystal molecules are aligned in such a manner as to fall toward the center of the pixel under the effect of the oblique electric field at the edge of the pixel electrode **22**. At the positions corresponding to the areas I of FIG. **68**, the projection **30** on the upper substrate (opposed substrate) **12** and the edge of the pixel electrode **22** form an obtuse angle, or the projection **32** on the pixel electrode **22** and the edge of the pixel electrode **22** assumes an acute angle.

In these areas, the alignment of the liquid crystal molecules is considerably different from the alignment of the liquid crystal molecules located inward of the edge (FIG. **67**), and therefore the display becomes dark as shown in FIG. **68**. Provision of the edge projections **80** as shown in FIG. **72**, however, causes the alignment of the liquid crystal molecules at the edge of the pixel electrode **22** to become similar to the alignment of the liquid crystal molecules located inward of the particular edge, thereby preventing the display from darkening. In FIG. **72**, corner projections **82** are also provided.

FIG. **73** shows a modification of the linearly arranged structures. This modification is similar to the modification of FIG. **72** except that the corner projections **82** are not included in this modification. Also in the cases of FIGS. **72** and **73**, a newly formed projection is extended to the projection on the pixel electrode. The height of the projection is 1.75 μm and no spacer is sprayed. The cell thickness of 3.5 μm is secured by partial contact between the projections of the two substrates.

FIG. **74** shows a modification of the linearly arranged structures. In this modification, the projection **30** has an additional projection **76**. At the same time, the projection **30**

and the slit structure **46** are configured of a plurality of constituent units (**30**S and **46**S) as in the case of FIG. **21**. In this case, therefore, the effect of configuring the linearly arranged structures of a plurality of constituent units and the effect of providing an additional linear wall structure are both obtained.

FIG. **75** is a view showing the relationship between the linearly arranged structures and polarizers of a liquid crystal display apparatus according to the sixth embodiment of the present invention. FIG. **16** is a view showing the display brightness in the configuration of FIG. **75**.

The liquid crystal display apparatus shown in FIG. **75** includes a configuration basically similar to that of the liquid crystal display apparatuses shown in FIGS. **1** to **10**. Specifically, the liquid crystal display apparatus comprises a pair of substrates **12** and **14**, a liquid crystal **16** having a negative anisotropy of its dielectric constant and inserted between the pair of the substrates **12** and **14**, linearly arranged structures (projections **30** and **32**, slits **44** and **46**, for example) provided on each of the pair of substrates **12** and **14** for controlling the alignment of the liquid crystal **16** and polarizers **26** and **28** arranged on the outside of the pair of substrates **12** and **14**, respectively. The pair of substrates **12** and **14** include the electrodes **18** and **22** and the vertical alignment layers **20** and **24**, respectively.

The linear wall structure for controlling the alignment of the liquid crystal in FIG. **75** is configured of projections similar to the projections **30** and **32** shown in FIG. **4**. The arrangement of the polarizers **26** and **28** is shown by numeral **48**. The polarizers **26** and **28** have absorption axes **26***a* and **28***a*, respectively. These absorption axes **26***a* and **28***a* cross at right angles to each other. The absorption axis **26***a* of one polarizer **26** (hence, also the absorption axis **28***a* of the other polarizer **28**) is arranged at a predetermined angle (a) displaced from the orientation rotated by 45 degrees from the orientation in which the projections **30** and **32** extend. To express it in more easily understood terms, in FIG. **75**, the absorption axis **26***a* of the polarizer **26** is arranged at an angle (45°±a) to the straight line (indicated by dashed line) crossing at right angles to the projections **30** and **32**, and hence at an angle (45°±a) to the orientation in which the projections **30** and **32** extend.

FIG. **75** shows the behavior of the liquid crystal molecules on the linearly arranged structures (projections **30** and **32**) for controlling the orientation of the liquid crystal. In a liquid crystal display apparatus having the linearly arranged structures (projections **30** and **32**, slits **44** and **46**) for controlling the alignment of the liquid crystal, as explained above with reference to FIGS. **11** and **13**, an overshoot occurs immediately after voltage application. One of the causes of the overshoot is that in the case where the polarizers **26** and **28** are arranged at 45° to the linearly arranged structures, the liquid crystal molecules fail to be, arranged in a position exactly perpendicular to the linearly arranged structures after voltage application and therefore the brightness of white display is reduced. This embodiment is intended to solve such a problem.

In FIG. **75**, upon application of a voltage thereto, the liquid crystal molecules located between the projections **30** and **32** fall into a position perpendicular to the projections **30** and **32**. The liquid crystal molecules on the projections **30** and **32** fall rightward or leftward in parallel to the projections **30** and **32**. As a result, the liquid crystal molecules located between the projections **30** and **32** do not assume a position exactly perpendicular to the projections **30** and **32** but a position somewhat oblique to the projections **30** and **32**. By way of explanation, the left area L and the right area R are shown distinctly in FIG. **75**. The liquid crystal molecules located in the left area L are rotated clockwise at an angle a to the line perpendicular to the projections **30** and **32** (the director of the liquid crystal for the left area L is the angle a), while the liquid crystal molecules located in the right area R are rotated counterclockwise.

In this embodiment, the polarizers **26** and **28** are arranged in accordance with the alignment of the liquid crystal molecules located in the left area L. The absorption axis **26***a* of the polarizer **26** is arranged at an angle of 45° to the director of the liquid crystal located in the left area L. Thus, as shown in FIG. **76**A, the brightest display can be realized at the time of white display in the left area L.

In the right area R, on the other hand, the same condition as realized in the left area L cannot be realized. Instead, as shown in FIG. **76**B, the brightest display cannot be realized at the time of white display. As shown in FIG. **76**C, however, as far as the entire display (L+R) combining the bright left area L and the right area R which darkens after being brightened once, a bright display can be realized at the time of white display, thereby making it possible to improve the overshoot considerably.

FIG. **77** is a view showing the relationship between the director angle a of the liquid crystal and the frequency thereof for each minor area in a liquid crystal display apparatus having linearly arranged structures (projections **30** and **32**, for example) for controlling the alignment of the liquid crystal. This indicates that the director of the liquid crystal becomes oblique generally in the range not more than 20°. Therefore, the predetermined angle a by which the absorption axis **26***a* of the polarizer **26** is displaced from the orientation rotated by 45 degrees from the orientation in which: the projections **30** and **32** extend is not more than 20°.

In this case, the crossing angle b, which is assumed to be the angle at which the direction of the absorption axis **26***a* of the polarizer **26** crosses the linearly arranged structures (projections **30** and **32**, for example), is in the range of 25°<b<45° or 45°<b<65°. Between the polarizers **26** and **28** and the substrates **12** and **14**, however, there is an error of about 2° derived from the relative positions at the time of manufacture. Taking this into account, the crossing angle b should be in the range of 25°<b<43° or 47°<b<58°.

More specifically, in FIG. **77**, the frequency of the director of the liquid crystal is high in the range of 2° to 13°. Therefore the predetermined angle a is desirably in the range between 2° and 13°. In this case, the crossing angle b should be in the range of 32°<b<43° or 47°<b<58°.

FIGS. **78** and **79** show a modification of the embodiment of FIG. **75**. FIG. **78** is a view showing the relationship between the linearly arranged structures and the polarizers of a liquid crystal display apparatus, and FIG. **79** is a cross-sectional view of the liquid crystal display apparatus shown in FIG. **78**. The upper substrate **12** has projections **30**, and the lower substrate **14** has projections **32**. The projections **30** and **32** have square bent portions. In this case, the absorption axis **26***a* of the polarizer **26** is arranged at an angle of 55° to the line sections of the projections **30**. The absorption axes **26***a* and **28***a* of the two polarizers **26** and **28** cross at right angles to each other.

FIGS. **80** and **81** are views showing a modification of the embodiment of FIG. **75**. FIG. **60** is a view showing the relationship between the linearly arranged structures and the polarizers of the liquid crystal display apparatus, and FIG. **81** is a cross-sectional view of the liquid crystal display

apparatus of FIG. **80**. The upper substrate **12** has projections **30**, and the lower substrate **14** has slits **46**. The projections **30** and the slits **46** have square bent portions. In this case, the absorption axis **26***a* of the polarizer **26** is arranged at an angle of 55° to the line sections of the projection **30** (or the slit **46**). The absorption axes **26***a* and **28***a* of the two polarizers **26** and **28** cross at right angles to each other.

FIG. **82** is a view showing the linearly arranged structures of the liquid crystal display apparatus according to the seventh embodiment of the present invention. FIG. **83** is a cross-sectional view of the liquid crystal display apparatus of FIG. **82**.

The liquid crystal display apparatus shown in FIGS. **82** and **83** comprises a pair of substrates **12** and **14**, a liquid crystal having a negative anisotropy of its dielectric constant and inserted between the pair of the substrates **12** and **14**, linearly arranged structures (projections **30** and **32** or slits **44** and **46**, for example) arranged on each of the pair of the substrates **12** and **14** for controlling the alignment of the liquid crystal **16**, and polarizers **26** and **28** arranged on the outside of the pair of the substrates **12** and **14**, respectively.

The lower substrate **14** is a TFT substrate, and the electrode **22** is pixel electrodes. The lower substrate **14** has TFTs **40** connected to the pixel electrode **22**. The TFT **40** is connected to a gate bus line and a drain bus line (FIG. **3**). A shielding area **84** covers the TFT **40** and the neighborhood thereof. The shielding area **84** is provided for preventing the TFT **40** from being exposed to direct light. The TFT **40** is in contact with the pixel electrode **22** and therefore the shielding area **84** is partially overlapped with the pixel electrode **22**.

The pixel electrode **22** defines a pixel aperture. However, the area occupied by the pixel electrode **22** but not overlapped with the shielding area **84** is not a pixel aperture. Thus, that portion of the area occupied by the pixel electrode **22** and not overlapped with the shielding area **84** constitutes a non-shielding area (pixel aperture).

In this example, the linearly arranged structures arranged on the upper substrate **12** are the projections **30**, and the linearly arranged structures arranged on the lower substrate **14** are the slits **46** formed on the electrode **22**. The projections **30** and the slits **46** are formed to have bent portions. Examples of combination of the projections **30** and the slits **46** are shown in FIGS. **71** and **74**.

The shielding area **84** and the linearly arranged structures **30** and **46** are arranged in such a manner that the shielding area **84** and a part of the linearly arranged structure **30** are partially overlapped to reduce the area of the linearly arranged structure **30** and **46** arranged in the non-shielding area.

As described above, the projection **30** is formed of a transparent dielectric material, and the slit **46** is formed in a transparent pixel electrode **22**. Therefore, the linearly arranged structure **30** and **47** can be regarded as transparent members. Nevertheless, in view of the fact that the liquid crystal molecules located on the linearly arranged structures **30** and **47** are aligned differently than the liquid crystal molecules located in the gap between the linearly arranged structure **30** and **47** upon application of a voltage thereto, the light transmission rate and the opening rate are reduced on the linearly arranged structure **30** and **47** in the pixel aperture at the time of white display upon application of a voltage thereto. Thus, the area of the linearly arranged structures **30** and **46** arranged in the non-shielding area (the pixel aperture) is desirably reduced. A predetermined area is required of the linearly arranged structures **30** and **46**, however, for controlling the alignment of the liquid crystal. In view of this, assuming that the area of the linearly arranged structures **30** and **46** is constant, a part of the linearly arranged structures **30** and **46** is relocated to a position overlapped with the shielding area **84** to reduce the area of the linearly arranged structures **30** and **46** arranged in the non-shielding area. In this way, the actual aperture rate can be increased. For this reason, in FIG. **82**, the shielding area **84** and the linearly arranged structures **30** and **46** are designed in such a manner that the projection **30** is partially overlapped with the shielding area **84**.

FIG. **84** is a view showing a specific example of the linearly arranged structures **30** and **46** of FIG. **82**. The feature of the apparatus shown in FIG. **84** is similar to that of the apparatus explained with reference to FIG. **82**. The source electrode of the TFT **40** is connected to the pixel electrode **22** by a contact hole **40***h*.

Further, as shown in FIGS. **82** to **84**, in the case where the linearly arranged structures of the substrate **14** having the TFTs **40** are slits **46**, the projections **30** (or the slits **44**) of the opposed substrate **12** is desirably overlapped with the shielding area **84** covering the TFT **40**. The slit **46** overlapped with the shielding area **84** may make it inconvenient to establish the contact between the TFT **40** and the pixel electrode **22**.

FIG. **85** is a view showing a comparative example of the linearly arranged structures of FIG. **82**. In this example, in the case where the linearly arranged structures of the substrate **14** having the TFTs **40** are the slits **46**, the TFT substrate **14** or the slit **46** is arranged to be overlapped with the shielding area **84** covering the TFT **40**. Once the slit **46** is overlapped with the shielding area **84**, however, it becomes difficult to connect the TFT **40** and the pixel electrode **22**. In other words, the slit **46** comes to occupy the position where a contact hole (**40***h* in FIG. **84**) is not to be formed.

FIG. **86** is a view showing a modification of the linearly arranged structures of FIG. **28**, and FIG. **87** is a cross-sectional view of the liquid crystal display apparatus having the linearly arranged structures of FIG. **86**. FIGS. **86** and **87** are views for explaining an example in which the electrode is removed from under the third projection in the left column of Table 1 described above. The projection **32** is formed on the electrode **22** of the substrate **14**, but the electrode **22** under the projection **32** is formed with a rhombic void **22***x*. The projection **32** can constitute the boundary forming means **56** of first type (I) due to the void **22***x* of the electrode **22**. The void **22***x* is not necessarily rhombic but may take other shapes such as rectangle.

FIG. **88** is a view showing the linearly arranged structures of the liquid crystal display apparatus according to an eighth embodiment of the invention. FIG. **89** is a cross-sectional view of the liquid crystal display apparatus having the linearly arranged structures of FIG. **88**. The embodiment of FIGS. **88** and **89** has a combined feature of the embodiment of FIG. **28** and the embodiment of FIG. **43**. Specifically, this embodiment comprises first means for forming the boundary of alignment of the liquid crystal in the linearly arranged structures of one substrate, and second means for forming the boundary of alignment of the liquid crystal at the same position as the first means in the other substrate along the extension of the linearly arranged structures.

The upper substrate **12** has the linearly arranged structures **30** formed of projections, and the lower substrate **14** has the linearly arranged structures **32** formed of projections. FIG. **89** is a cross-sectional view taken along a line passing through the linearly arranged structures **32** formed of the

projections of the lower substrate **14**. The projection **32** has separation sections **32**T, thereby forming the boundary forming means **58** of second type (II) on the projection **32**. Further, the opposed substrate **12** is formed with dot-projections **62***a* at positions opposed to the separation sections **32**T, respectively. As explained with reference to FIG. **43**, the dot-projections **62***a* of the opposed substrate **12** are means **62** for forming the boundary of alignment of the liquid crystal molecules at a predetermined position and have the same function of controlling the liquid crystal alignment as the boundary forming means **58** of second type (II). In this case, therefore, the two boundary forming means **58** and **62** of second type (II) are arranged at the same position thereby to secure the formation of the boundary of second type (II) more positively. Thus, the alignment of the liquid crystal molecules is assured further.

FIGS. **90** and **91** are views showing an example analogous to FIGS. **88** and **89**. This modification also includes the boundary forming means **58** of second type (II), and the opposed substrate **12** includes the means **62** for forming the boundary of alignment of the liquid crystal molecules at a predetermined position. In the embodiment of FIGS. **90** and **91**, the size relationship between the separation sections **32**T of the projection **32** constituting the means **58** and the projections **62***a* constituting the means **62** is different from the corresponding relation in FIGS. **88** and **89**.

FIG. **92** is a view showing a modification of the linearly arranged structures of FIG. **88**. FIG. **93** is a cross-sectional view showing the linear wall structure (projection) **32** of FIG. **92**. This linearly arranged structure (projections) **32** includes the boundary forming means **56** of first type (I) formed by increasing the height of the projection **32** and the boundary forming means **58** of second type (II) formed by reducing the height of the projection **32** as shown in FIG. **32**. The opposed substrate **12** includes the boundary forming means **62** at the same position as the means **56**, **58**.

FIG. **94** is a view showing a modification of the linearly arranged structures of FIG. **93**. This linearly arranged structures (projections) **32**, as shown in FIG. **35**, include the boundary forming means **56** of first type (I) formed by widening the projection **32** and the boundary forming means **58** of second type (II) formed by narrowing the width of the projection **32**. The opposed substrate **12** can include the boundary forming means **62** at the same position as the means **56**, **58**.

FIGS. **95** and **96** are views showing an example similar to FIGS. **88** and **89**. In this example also, the projection **32** includes the boundary forming means **56** of a first type (I) and the boundary forming means **58** of a second type (II), and the opposed substrate **12** includes the means **62** for forming the boundary of alignment of the liquid crystal molecules at the same predetermined position as the means **56** and **58**. The boundary forming means **56** of first type (I) constitutes a separation section of the projection **32** and the boundary forming means **58** of a second type (II) constitutes a portion increased in height on the projection **32**.

FIG. **97** is a view showing a modification of the linearly arranged structures of FIG. **88**. In this example, the linearly arranged structures of the lower substrate **14** are formed as slits **46**. The slits **46** are separated by the walls **58***a*, and constitute the boundary forming means **58** of second type (II). At the same time, each wall **58***a*, to cooperate as a protruded wall, constitutes the means **62** for forming the boundary of alignment of the liquid crystal molecules at a predetermined position on the linearly arranged structures (projections) **30**.

FIG. **98** is a view showing linearly arranged structures analogous to FIG. **97**. In this example, the linearly arranged structures of the lower substrate **14** are formed as slits **46** separated by walls **58***a*. The walls **58***a* are located at the separation sections and the intermediate portions of the component parts of the separated linear wall structure (projections) with which the walls **58***a* are to cooperate, and constitute the boundary forming means **58** of first type (I) and the boundary forming means **58** of second type (II). At the same time, the wall **8***a*, to cooperate as a protruded wall, constitutes the means **62** for forming the boundary of alignment of the liquid crystal molecules at a predetermined position on the linearly arranged structures (projection) **30**.

The embodiments described above with reference to FIGS. **88** to **98** can be summarized as follows. (a) As the boundary forming means **56** of first type (I), the projections **30** and **32** are thickened or increased in height and the slits **44** and **46** are thickened or increased in height, while as the boundary forming means **60** and **62** for the opposed substrate, a dot-projection, a partially cut projection, a partially thinned projection, a partially lowered projection, a partially connected projection, a partially thinned slit or a partially lowered slit are provided. (b) As the boundary forming means **58** of second type (II), the projections **30**, **32** are cut (into a plurality of constituent units), thinned or reduced in height, and the slits **44**, **46** are cut, thinned or reduced in height. As the boundary forming means **60**, **62** for the opposed substrate, on the other hand, a dotted projection, a partially thickened projection, a projection partially increased in height, a partially protruded projection, a partially thickened projection or a dotted electrode recess is formed.

FIG. **99** is a view showing the linearly arranged structures of the liquid crystal display apparatus according to the ninth embodiment of the present invention. In this case, as in the preceding embodiment, the liquid crystal display apparatus comprises a pair of substrates **12** and **14**, a liquid crystal **16** having a negative anisotropy of its dielectric constant and inserted between the pair of the substrates **12** and **14**, linearly arranged structures (such as projections **30** and **32** or slits **44** and **46**) arranged in each of the pair of the substrates **12** and **14** for controlling the alignment of the liquid crystal **16**, and polarizers **26** and **28** arranged on the outside of the pair of the substrates **12** and **14**.

FIG. **99** shows one linearly arranged structure (projection) **30** of the upper substrate **12** and one linearly arranged structure (projection) **32** of the lower substrate **14**. The linearly arranged structure **30** of the upper substrate includes the means **86** similar to the means **56** for forming the boundary of alignment of first type with the liquid crystal molecules around a point are directed to said point as described above with reference to FIG. **28**, and the linearly arranged structure **32** of the lower substrate also includes the means **86** for forming the boundary of alignment of first type with the liquid crystal molecules around a point are directed to said point.

At the time of voltage application, as described previously, the liquid crystal molecules on the linearly arranged structures **30** of the upper substrate and the liquid crystal molecules on the linearly arranged structures **32** of the lower substrate are aligned in the direction parallel to the linearly arranged structure **30** and **32**, respectively. On the other hand, the liquid crystal molecules located in the gap between the linearly arranged structures **30** of the upper substrate and the linearly arranged structures **32** of the lower substrate are aligned perpendicular to the linearly arranged structures **30** and **32**.

Further, among the liquid crystal molecules on the linearly arranged structures **30** of the lower substrate, those liquid crystal molecules located in the area on the left side of the boundary forming means **86** are aligned rightward with the head thereof directed toward the boundary forming means **86** as indicated by arrow, while the liquid crystal molecules located in the area on the right side of the boundary forming means **86** are aligned leftward with the head thereof directed toward the boundary forming means **86** as indicated by arrow. In similar fashion, among the liquid crystal molecules on the linearly arranged structures **32** of the lower substrate, those liquid crystal molecules located in the area on the left side of the boundary forming means **86** are aligned leftward with the head thereof directed away from the boundary forming means **86** as indicated by arrow, while the liquid crystal molecules located in the area on the right side of the boundary forming means **86** are oriented with the head thereof directed rightward away from the boundary forming means **86** as indicated by arrow.

With regard to the liquid crystal molecules located on a line perpendicular to the linearly arranged structures **30** and **32** (those liquid crystal molecules located in the area on the left side of the boundary forming means **86** surrounded by a dotted circle, for example), the liquid crystal molecules on the linearly arranged structures **30** are aligned rightward (first direction), and the liquid crystal molecules located on the linearly arranged structures **32** are aligned leftward (in the second direction opposite to the first direction). In other words, among the liquid crystal molecules located in the area on the left side of the boundary forming means **86**, those liquid crystal molecules located on the linearly arranged structures **30** are aligned in the direction opposite to the liquid crystal molecules located on the linearly arranged structures **32**. Similarly, among the liquid crystal molecules located in the area on the right side of the boundary forming means **86**, the liquid crystal molecules located on the linearly arranged structures **30** are aligned in the direction opposite to the liquid crystal molecules located on the linearly arranged structures **32**.

FIG. **100** is a view showing a modification of the linearly arranged structures of FIG. **99**. In this case, the linearly arranged structures **30** and **32** both include means **88** similar to the means **58** for forming the boundary of alignment of second type in which part of the liquid crystal molecules around a point are directed toward said point and the other liquid crystal molecules are aligned in the opposite direction from the same point. With regard to the liquid crystal molecules on the linearly arranged structures **30** of the upper substrate, therefore, those liquid crystal molecules located in the area on the left side of the boundary forming means **88** are aligned leftward with the head thereof directed away from the boundary forming means **88**, as indicated by arrow, while those liquid crystal molecules located in the area on the right side of the boundary forming means **88** are oriented, as indicated by arrow, rightward with the head thereof directed away from the boundary forming means **88**. In similar fashion, among the liquid crystal molecules on the linearly arranged structures **32** of the lower substrate, those liquid crystal molecules located in the area on the left side of the boundary forming means **88** are aligned, as indicated by arrow, rightward with the head thereof directed toward the boundary forming means **88**, while those liquid crystal molecules located in the area on the right side of the boundary forming means **88** are aligned, as indicated by arrow, leftward with the head thereof directed toward the boundary forming means **88**.

Taking the liquid crystal molecules located on a line perpendicular to the linearly arranged structures **30** and **32**, as an example, the liquid crystal molecules on the linearly arranged structures **30** are aligned in the first direction, while the liquid crystal molecules on the linearly arranged structures **32** are aligned in the second direction opposite to the first direction.

FIG. **101** is a view for explaining the problem of operating by finger a liquid crystal display apparatus having the linearly arranged structures **30** and **32**. FIG. **101** shows the state in which a point D on the image display screen is pressed by a finger. In the case where the point D on the image display screen is pressed by a finger, the trace of the finger may be left at the point D as a display defect. The finger trace disappears when the voltage application is stopped. Even when the voltage application is continued, the finger trace may disappear within a short voltage application time or may remain after a protracted voltage application. No problem is posed in the case where the liquid crystal display apparatus is used as an apparatus in which no external force is applied such as by finger. For a liquid crystal display apparatus such as a touch panel in which an external force is applied by finger or the like, on the other hand, the problem of finger trace being left on the display screen is posed.

FIG. **102** is a view showing a typical example in which a finger trace is liable to occur. The linearly arranged structures **30** of the upper substrate includes means **86** for forming the boundary of alignment of first type, and the linearly arranged structures **32** of the lower substrate includes means **88** for forming the boundary of alignment of second type in which some liquid crystal molecules around a point are directed to said point while the other liquid crystal molecules are directed in the opposite direction from the same point. The liquid crystal molecules on the linearly arranged structures of the upper substrate **30** are thus aligned in the same direction as the liquid crystal molecules on the linearly arranged structures **32** of the lower substrate. Among the liquid crystal molecules on the linearly arranged structures **30** of the upper substrate, for example, the liquid crystal molecules located in the area on the left side of the boundary forming means **86** are aligned leftward, while among the liquid crystal molecules on the linearly arranged structures **32** of the lower substrate, the liquid crystal molecules located in the area on the left side of the boundary forming means **88** are aligned leftward.

In the case where the image display screen is pressed by finger, the liquid crystal molecules on the linearly arranged structures **30** and **32** move toward the gap between the linearly arranged structures **30** and **32**, so that a part **16***m* of the liquid crystal molecules in the gap between the linearly arranged structures **30** and **32** are aligned in the direction parallel to the linearly arranged structures **30** and **32**. The liquid crystal molecules in the gap between the linearly arranged structures **30** and **32** are originally required to be perpendicular to the linearly arranged structures **30** and **32**. At the portion pressed by finger, however, the part **16***m* of the liquid crystal molecules in the gap between the linearly arranged structures **30** and **32** is aligned parallel to the linearly arranged structures **30** and **32**. Thus, a declination occurs resulting in the finger trace being left.

As shown in FIG. **102**, in the case where the liquid crystal molecules on the linearly arranged structures **30** and **32** of the two substrates are aligned in the same direction, the liquid crystal molecules that have moved toward the gap between the linearly arranged structures **30** and **32** from the linearly arranged structures **30** and **32** are aligned in the same direction as the liquid crystal molecules on the linearly arranged structures **30** and **32**. These liquid crystal mol-

ecules are aligned continuously from the linearly arranged structure **30** through the gap between the linearly arranged structures **30** and **32** to the other linearly arranged structures **32**, so that the finger trace is left for a long time.

In the case where the image display screen is pressed by finger in FIGS. **99** and **100**, on the other hand, as in the case of FIG. **102**, a part **16***m* of the liquid crystal molecules on the linearly arranged structures **30** and **32** is pushed out toward the gap between the linearly arranged structures **30** and **32** into a position parallel to the linearly arranged structures **30** and **32**. In this case, however, the liquid crystal molecules on the linearly arranged structures **30** and **32** of the two substrates are aligned in opposite directions. Therefore, the liquid crystal molecules **16***m* that have been pushed out are aligned in the same direction as the liquid crystal molecules on the linearly arranged structures of one substrate, but in the direction opposite to the liquid crystal molecules on the linearly arranged structures of the other substrate and fail to be continuously aligned with the liquid crystal molecules on the other linearly arranged structures. Adjacent liquid crystal molecules must be continuously aligned, and therefore the liquid crystal molecules **16***m* pushed out tend to rotate in the direction perpendicular to the linearly arranged structures **30** and **32** as indicated by an arrow. As a result, the finger trace disappears within a short time.

FIGS. **103** and **104** are view showing an example of the boundary forming means **86** of FIG. **99**. The linearly arranged structures **30** of the upper substrate are projections. As to the linearly arranged structures **30** of the upper substrate **12**, the means **86** for forming the boundary of alignment of second type (II) includes a small projection **86***a* arranged on the lower substrate **14**. The linearly arranged structures **32** of the lower substrate **14** are projections. With regard to the linearly arranged structures **32** of the lower substrate **14**, the means **86** for forming the boundary of alignment of second type (II) includes a small projection **86***b* arranged on the upper substrate **12**. The small projection **86***a* and the small projection **86***b* are arranged on a line perpendicular to the linearly arranged structures **30** and **32**.

FIGS. **105** and **106** are views showing an example of the boundary forming means **88** of FIG. **100**. The linearly arranged structures **30** of the upper substrate are projections. With regard to the linearly arranged structure **30** of the upper substrate **12**, the means **88** for forming the boundary of alignment of first type (I) includes a small projection **88***a* arranged on the upper substrate **12**. The linearly arranged structure **32** of the lower substrate **14** is a projection, and with regard to the linearly arranged structure **32** of the lower substrate **14**, the means **88** for forming the boundary of alignment of first type (I) includes a small projection **88***b* arranged on the lower substrate **14**. The small projection **88***a* and the small projection **88***b* are arranged on a line perpendicular to the linearly arranged structures **30** and **32**. In FIGS. **103** to **106**, the small projections **86***a* and **86***b* are longer than the width of the linearly arranged structures **30** and **32** and extend in the direction at right angles to the linearly arranged structures **30** and **32**. The width of the linearly arranged structures **30** and **32**, for example, is 10 μm and the height thereof is 1.5 μm. The width of the small projections **86***a* and **86***b* is 10 μm, the height thereof is 1.5 μm and the length thereof is 14 μm. The small projections **86***a* and **86***b* can be formed of a dielectric material.

FIG. **107** is a view showing an example of the boundary forming means **86** of FIG. **99**. The linearly arranged structure **30** of the upper substrate is a projection, and with regard to the linearly arranged structure **30** of the upper substrate **12**, the means **86** for forming the boundary of alignment of

first type includes a small slit **86***c* formed in the electrode of the lower substrate **14**. The linearly arranged structure **32** of the lower substrate **14** is a projection, and with regard to the linearly arranged structure **32** of the lower substrate, the means **86** for forming the boundary of alignment of second type includes a small slit **86***d* formed in the electrode of the upper substrate **12**. The small slit **86***c* and the small slit **86***d* are arranged on a line perpendicular to the linearly arranged structures **30** and **32**.

FIG. **108** is a view showing an example of the means **88** of FIG. **100**. The linearly arranged structure **30** of the upper substrate is a projection, and the means **88** for forming the boundary of alignment of second type on the linearly arranged structure of the upper substrate **12** includes a small slit **88***c* formed in the upper substrate **12**. The linearly arranged structure **32** of the lower substrate **14** is a projection, and the means **88** for forming the boundary of alignment of second type on the linearly arranged structure **32** of the lower substrate **14** includes a small slit **88***d* formed in the lower substrate **14**. The small slit **88***c* and the small slit **88***d* are arranged on a line perpendicular to the linearly arranged structures **30** and **32**. In FIGS. **107** and **108**, the small slits **88***c*, **88***d* are longer than the width of the linear wall structure **30**, **32** and extend in the direction at right angles to the linearly arranged structures **30** and **32**.

In FIGS. **99** to **108**, projections are shown as the linearly arranged structures **30** and **32**. As an alternative, slits may of course be used as the linearly arranged structures **30** and **32**. In this case too, small projections or small slits can be used as the means **86** and **88**. Also, the two means **86** including the upper substrate and the lower substrate may be a combination of a small projection and a small slit, and the two means **88** including the upper substrate and the lower substrate may be a combination of a small projection and a small slit. In this way, according to this embodiment, a liquid crystal display apparatus having a high shock resistance is obtained.

FIG. **109** is a view showing the linearly arranged structures of a liquid crystal display apparatus according to the tenth embodiment of the invention. FIG. **110** is a cross-sectional view of the liquid crystal display apparatus of FIG. **109**. Also in this case, as in the preceding embodiment, the liquid crystal display apparatus comprises a pair of substrates **12** and **14**, a liquid crystal having a negative anisotropy of its dielectric constant and inserted between the pair of the substrates **12** and **14**, linearly arranged structures (such as projections **30** and **32** or slits **44** and **46**) arranged on each of the pair of the substrates **12** and **14**, respectively, for controlling the alignment of the liquid crystal **16**, and polarizers (not shown) arranged on the outside of the pair of the substrates **12** and **14**, respectively.

According to this embodiment, the linearly arranged structures **30** of the upper substrate **12** are a projections **30**, and the linearly arranged structures **32** of the lower substrate **14** are projections **32**. Auxiliary wall structures **90** are arranged on the lower substrate **14** between the linearly arranged structures **30** and **32** of the pair of the substrates **12** and **14**, as viewed in the direction normal to the pair of the substrates **12** and **14**. The auxiliary wall structures **90** are arranged as rhombic slits. The auxiliary wall structures **90** are long in the direction perpendicular to the linearly arranged structures **30** and **32**, and arranged at predetermined pitches (5 to 50 μm) along the linearly arranged structures **30** and **32**.

FIG. **111** is a view showing a modification of the liquid crystal display apparatus of FIG. **109**. In this example, the

linearly arranged structures **30** of the upper substrate **12** are projections **30**, and the linearly arranged structures **32** of the lower substrate **14** are projections **32**. The auxiliary wall structures **90** interposed between the linearly arranged structures **30** and **32** of the pair of the substrates **12** and **14** are arranged as rectangular slits. The auxiliary wall structures **90** are long in the direction perpendicular to the linearly arranged structures **30** and **32**, and are arranged at predetermined pitches along the linearly arranged structures **30** and **32**.

FIGS. **112** and **113** are views showing a modification of the liquid crystal display apparatus of FIG. **109**. In this example, the linearly arranged structures **30** of the upper substrate **12** are projections **30**, and the linearly arranged structures **32** of the lower substrate **14** are projections **32**. The auxiliary wall structures **90** interposed between the linearly arranged structures **30** and **32** of a pair of the substrates **12** and **14** are provided as square projections. The auxiliary wall structures **90** are arranged at predetermined pitches along the linearly arranged structures **30** and **32**.

FIGS. **114** and **115** are views showing a modification of the liquid crystal display apparatus of FIG. **109**. In this example, the linearly arranged structures **30** of the upper substrate **12** are projections **30**, and the linearly arranged structures **32** of the lower substrate **14** are projections **32**. Each auxiliary wall structure **90** interposed between the linearly arranged structures **30** and **32** of the pair of the substrates **12** and **14** is arranged as a rectangular slit. The auxiliary wall structure **90** is long in the direction perpendicular to the linearly arranged structures **30** and **32** and is arranged at predetermined pitches along the linearly arranged structures **30** and **32**.

The operation of the liquid crystal display apparatus shown in FIGS. **109** to **115** will be explained. In a liquid crystal display apparatus comprising the linearly arranged structures **30** and **32** on the pair of the substrates **12** and **14** for controlling alignment of the liquid crystal, no rubbing is required and the visual angle characteristic is improved. In view of the fact that the distance is large between the linearly arranged structures **30** and **32** in cooperative relation, however, the response of the liquid crystal is low upon application of a voltage thereto. The provision of the auxiliary wall structures **90** between the linearly arranged structures **30** and **32** facilitates the alignment of the liquid crystal in the gap between the linearly arranged structures **30** and **32** and thus improves the response of the liquid crystal as compared when the auxiliary wall structures **90** are absent.

More specifically, in the liquid crystal display apparatus comprising the linearly arranged structures **30** and **32** on the pair of the substrates **12** and **14**, the liquid crystal molecules are aligned in the direction perpendicular to the substrate surface and fall in a predetermined direction upon application of a voltage thereto. The liquid crystal molecules located at an intermediate position between the linearly arranged structure **30** and **32** in cooperative relation will not lie in a fixed direction but tend to lie in a random direction immediately after voltage application. With the lapse of a predetermined time, however, the molecules lie in a predetermined direction. The result is a lower response. In the presence of the auxiliary wall structure **90**, the liquid crystal molecules located intermediate between the linearly arranged structures **30** and **32** in cooperative relation lie in a predetermined direction immediately after voltage application, thereby improving the responsiveness.

FIGS. **109** to **115** show examples in which both the linearly arranged structures **30** and **32** are formed as projections, for which the auxiliary wall structures **90** including projections or slits are provided. The linearly arranged structures **30** and **32** are both formed as slits. As an alternative, linearly arranged structures of one substrate are formed as projections, and the linearly arranged structures of the other substrate formed as slits. Also in this case, the auxiliary wall structures **90** can be configured of projections or slits. The projections and the slits have substantially the same function and substantially the same effect on the liquid crystal alignment. The auxiliary wall structures **90**, therefore, may be either projections or slits. Although no geometric restriction exists, the rhombus produces a good result.

In the case where slits are formed as the auxiliary wall structures **90**, the slit should be as long as possible and substantially as long as the gap between the linearly arranged structures **30** and **32** in the direction perpendicular to the linearly arranged structures **30** and **32** in order to heighten the effect of the slits. The slits, if lengthened in the direction parallel to the linearly arranged structures **30** and **32**, reduce the area of the electrode portion (in the case where the slit is arranged on the electrode), while if too short, makes it difficult to form the slit itself. The desirable length, therefore, is about 5 to 10 μm. As to the distance between the slits, the effect of the slits is reduced if the distance are too long, while too short a distance disturbs the orientation of the liquid crystal under the mutual effect of the slits. The distance of 5 to 30 μm is recommended.

In the case where projections are formed as the auxiliary wall structures **90**, the conditions to be met are somewhat different from those for the slits. First, the size of the projections should not be too large, otherwise the transmittance of the liquid crystal display apparatus is reduced. Too short a projection, on the other hand, makes it difficult to form the projection itself and reduces the effect at the same time. The length of about 5 μm is desirable in the directions both perpendicular and parallel to the linear wall structure **30**, **32**. As to the distance between the projections, about 5 to 30 μm is desirable for the same reason as in the case of the slit on the one hand and in order not to sacrifice the transmittance on the other.

The use of conductive projections as the auxiliary wall structures **90** is more desirable as it can widen the distance between the projections without sacrificing the transmittance. At the same time, the distance between the projections can be increased up to about 50 μm. For forming conductive projections, ITO is sputtered after forming the projection on the substrate lacking the ITO electrode.

In the case where slits or projections are formed as the auxiliary wall structures **90**, the auxiliary wall structures **90** are not necessarily arranged on both the substrates **12** and **14** but only one of them.

FIGS. **116**A to **116**G are views showing a method of fabricating the substrate **14** having the linearly arranged structures **32** and the auxiliary wall structures **90**. As shown in FIG. **116**A, the substrate **14** formed with an ITO film is prepared first. In the case where the substrate **14** is a TFT substrate, the TFT and an active matrix are formed on the substrate followed by forming an ITO film. A positive resist (LC200 made by Sciplay Far East) **91** is spin coated on the substrate **14** at 1500 rpm for 30 seconds. The resist is not necessarily positive, but may be negative. Further, a photosensitive resin may be used instead of resist. The spin-coated resist **91** is prebaked at 90° C. for 20 minutes, after which the resist **91** is subjected to contact exposure through a photomask **92** for ITO patterning (exposure time 5 seconds).

As shown in FIG. **116**B, the resist **91** is developed (the development time 50 seconds) with the developer MF319 of Sciplay Far East, followed by two post-baking sessions at 120° C. for one hour and at 200° C. for forty minutes. As shown in FIG. **116**C, the ITO of the substrate **14** is etched (etching time 3 minutes) using an ITO etchant (mixture solution of iron chloride, hydrochloric acid and pure water) heated to 45° C. As shown in FIG. **116**D, the resist **91** is separated using acetone thereby to produce a substrate **14** with ITO electrode having auxiliary wall structures (slits) **90** patterned thereon.

The patterned ITO constitutes the pixel electrodes **22**. It follows, therefore, that the auxiliary wall structures (slits) **90** are formed on the pixel electrodes **22**. The auxiliary wall structures (slits) **90** thus produced are rectangular in shape having the longer side of 20 μm and the shorter side of 5 μm with the longer side crossing at right angles to the linear wall structure **32**. Also, the distance between the auxiliary wall structures (slits) **90** are 10 μm in the direction perpendicular to the linearly arranged structures **32** and 20 μm in the direction parallel to the linear wall structure **32**.

As shown in FIG. **116**E, the resist (LC200) **93** is spin coated in similar fashion to the preceding case on the substrate **14** patterned with the ITO electrode thus prepared, and after exposure through a photomask **94** for projection, the linearly arranged structures (projections) **32** are formed. In the process, the auxiliary wall structures (slits) **90** of the ITO electrode are located between the linearly arranged structures **30** and **32**. FIG. **116**F shows the linearly arranged structures (projections) **30** and **32** thus formed. The linearly arranged structures (projections) **32** have the width of 10 μm and the height of 1.5 μm and, when the upper and lower substrates **12** and **14** are laid one on the other, the interval of the linearly arranged structures **30** and **32** is 20 μm. Instead of the auxiliary wall structures (slits) **90** as in the case under consideration, the linearly arranged structures (projections) **32** can be formed first.

Then, the vertical alignment layers JALS684 (made by JSR) is spin coated at 200 rpm for 30 seconds, followed by baking at 180° C. for one hour. One substrate is formed with a seal (XN-21F, made by Mitsui Toatsu Chemical), and the other substrate is sprayed with a spacer (SP-20045, made by Sekisui Fine Chemical) of 4.5 μm. The resulting two substrates **12**, **14** are laid one on the other (FIG. **116**G). In the last step, an empty panel is produced by baking at 135° C. for 90 minutes. The liquid crystal MJ961213 (made by Merck) having a negative dielectric constant anisotropy is injected into the empty panel in a vacuum environment. Then, the injection port is sealed with a sealer (30Y-228, made by Three Bond) thereby to complete a liquid crystal panel (FIG. **116**G).

In this case, the distance between the auxiliary wall structures (slits) **90** are 20 μm in the direction parallel to the linearly arranged structures **32**. By a similar fabrication method, a liquid crystal display apparatus is prepared which has the auxiliary wall structures (slits) **90** with distance of 20 μm in the direction parallel to the linearly arranged structures **32**.

FIGS. **117**A to **117**E are views showing another example of the method for fabricating a substrate having linearly arranged structures and auxiliary wall structures. AS shown in FIG. **117**A, a positive resist (LC200, made by Sciplay Far East) **90***a* is spin coated on the substrate **14** having the ITO electrode (not shown) at 2000 rpm for 30 seconds. The resist **90***a* thus spin-coated is prebaked at 90° C. for 20 minutes, followed by contact exposure through a photomask **92***a* (exposure time 5 seconds).

As shown in FIG. **117**B, the resist **90***a* is developed with the developer MF319 of Sciplay Far East (development time 50 seconds), followed by post-baking at 120° C. for one hour and again at 200° C. for 40 minutes to thereby form the auxiliary wall structures (projections) **90**. These auxiliary wall structures have a size of 5 μm square, a height of 1 μm and a distance between projections of 25 μm (FIG. **117**C).

As shown in FIG. **117**D, the resist (LC200) **93** is spin coated in similar fashion on the substrate **14** thus prepared and, by exposure through the photomask **94** for forming a projection, the auxiliary wall structures (projections) **90** are arranged between the linearly arranged structures **30** and **32**. In a similar manner, the other substrate **12** is formed, and the upper and lower substrates are laid one on the other (FIG. **117**E). The linearly arranged structures (projections) **32** have a width of 10 μm, a height of 1.5 μm, and the interval of 20 μm between the linear wall structure **30**, **32** when the upper and lower substrates **12**, **14** are laid one on the other.

According to yet another example, the auxiliary wall structures **90** are formed of conductive projections. A method of fabricating this will be explained. As in the preceding case, auxiliary wall structures (projections) **90** are formed by use of a positive resist (LC200, made by Sciplay Far East) on a pair of the substrates lacking the ITO electrode. These auxiliary wall structures (projections) **90** have a size of 5 μm square, a height of 1 μm, and the inter-projection distance of 25 μm in the direction perpendicular to the linearly arranged structures **32** and **501***m* in the direction parallel thereto. Then, the ITO is sputtered on the substrate **14** having the auxiliary wall structures (projections) **90**, thus forming the pixel electrodes **22** by etching. The auxiliary wall structures (projections) **90** are covered by the ITO and formed as conductive projections. Then, the linearly arranged structures (projections) **32** are formed, and the two substrates **12** and **14** are laid one on the other. The linearly arranged structures (projections) **32** can of course be formed first.

FIG. **118** is a view showing the response of the liquid crystal display apparatus of FIG. **111**, in which the distance between the auxiliary wall structures (slits) **90** are changed to 10, 20, 30, 50 μm while maintaining a constant width (5 μm) of the auxiliary wall structures (slits) **90**. The measurement is taken at 25° C. The comparative example is the linearly arranged structures **30** and **32**, and reference is made to a liquid crystal display apparatus having no auxiliary wall structures (slits) **90**. The measurement shows that when the distance between the auxiliary wall structures (slits) **90** is 10, 20, 30 μm, the response speed is smaller than the response speed of the comparative example, while in the case where the distance between the auxiliary wall structures (slits) **90** are 50 μm, the response speed is larger than the speed of the comparative example. Thus, the distance between the auxiliary wall structures (slits) **90** are desirably not more than 50 μm or, more accurately, not more than 30 μm. Also, the transmittance is considerably reduced for the distance between the auxiliary structures (slits) **90** of 10 μm or less. Thus the lower limit of the distance between the auxiliary wall structures (slits) **90** is about 5 μm taking the resolution of the resist into account. By the way, the transmittance for respective distances between the auxiliary structures (slits) is as follows:

Comparative example	10 μm	20 μm	30 μm	50 μm
24.0%	22.7%	23.5%	23.8%	24.2%

FIG. **119** is a view showing the response of the liquid crystal display apparatus of FIG. **111** in which the distance between the auxiliary wall structures (slits) **90** is kept constant (20 μm) while the width of the auxiliary wall structures (slits) **90** changed to 5, 10 and 20 μm. This measurement shows that in the case where the width of the auxiliary wall structures is 5, 10 and 20 μm, the response speed is smaller than the response speed of the comparative example. For a width of not less than 20 μm of the auxiliary wall structures (slits) **90**, the transmittance is reduced. Thus, the width of the auxiliary wall structures (slits) **90** is desirably about 5 to 10 μm. By the way, the transmittance for each width of the auxiliary wall structures (slits) **90** is as follows:

Comparative example	5 μm	10 μm	20 μm
24.0%	23.5%	22.7%	20.8%

FIG. **120** is a view showing the response with the distance between the auxiliary wall structure (projections) **90** are changed to 10, 20, 50 and 70 μm with a fixed size (5 μm square) of the auxiliary wall structures (projections) **90** of the liquid crystal display apparatus of FIG. **112**. This measurement shows that in the case where the distance between the auxiliary wall structures (projections) **90** are 70 μm, the response speed is larger than the response speed of the comparative example. Thus, the distance between the auxiliary wall structures (projections) **90** are desirably not more than 50 μm. When the distance between the auxiliary wall structures (projections) **90** are reduced below 10 μm, on the other hand, the transmittance is reduced. Therefore, the lower limit of the distance between the auxiliary structures (projections) **90** is about 5 μm considering the resolution of the resist. The transmittance for each interval of the auxiliary wall structures (projections) **90** is as follows:

Comparative example	10 μm	20 μm	50 μm	70 μm
24.0%	22.3%	23.1%	23.8%	24.2%

FIG. **121** is a view showing the response of the liquid crystal display apparatus of FIG. **112**, in which the size of the auxiliary wall structures (projections) **90** is changed to 5 or 10 μm square with fixed distance between the auxiliary wall structures (projections) **90** at 20 μm. The measurement shows that the response speed for 5 μm in size of the auxiliary wall structures (projections) **90** is substantially the same as that for 10 μm in size of the auxiliary wall structures (projections) **90**. When the size of the auxiliary wall structure (projections) **90** is 5 μm, however, the transmittance is reduced. Desirably, therefore, the size of the auxiliary wall structures (projections) **90** is about 5 μm. The transmittance for each size of the auxiliary wall structures (projections) **90** is as follows:

Comparative example	5 μm	10 μm
24.0%	23.1%	20.6%

FIG. **122** is a view showing a liquid crystal display apparatus according to the eleventh embodiment of the present invention. In this case, as in the preceding embodiment, the liquid crystal display apparatus comprises a pair of substrates **12** and **14**, a liquid crystal **16** having a negative anisotropy of dielectric constant and inserted between the pair of the substrates **12** and **14**, linearly arranged structures (projections **30** and **32** or the slits **44** and **46**, for example) provided on each of the pair of the substrates **12** and **14** for controlling the alignment of the liquid crystal **16**, and polarizers **26** and **28** arranged on the outside of the pair of the substrates **12** and **14**, respectively.

FIG. **122** shows one linearly arranged structure (projection) **30** of the upper substrate **12**, and one linearly arranged structure (projection) **32** of the lower substrate **14**. Further, an auxiliary wall structure **96** is arranged between the linearly arranged structures **30** and **32** of the substrate pair at least as viewed along the normal to the substrate pair. According to this embodiment, the auxiliary wall structure **96** is formed on the lower substrate **14** as a substantially flat band-shaped projection **96A** wider than the linearly arranged structure **32** in the direction parallel to the linearly arranged structure **32**. The linearly arranged structure **32** is formed as a two-stage projection on the auxiliary wall structure **96**. The parameter changing in one direction is the height of the band-shaped projection **96A**.

With this configuration, the liquid crystal is aligned obliquely at the side edge of the auxiliary wall structure **96**. Further, in the case where dielectric constant of the auxiliary wall structure **96** is smaller than the dielectric constant of the liquid crystal, the application of an electric field causes the electric field (electric lines of force EL) to be inclined thereby causing the liquid crystal to align obliquely due to the difference between the dielectric constant of the auxiliary wall structure **96** and the dielectric constant of the liquid crystal. The inclination of the liquid crystal is restricted by the auxiliary wall structure **96** as well as by the linearly arranged structures **32**, so that the inclination of the liquid crystal immediately propagates through all the pixels immediately after voltage application, thereby shortening the response time.

FIG. **123** is a view showing a modification of the liquid crystal display apparatus of FIG. **122**. This modification includes conductive projections **96B** arranged on the substrate **12** in an opposed relationship to the linearly arranged structures **32**. The parameter changing in one direction is the height of the conductive projection **96B** formed in the opposed substrate **12**. The liquid crystal is aligned obliquely at the side edge of the conductive projections **96B**. Further, in view of the shape of the conductive projections **96B**, application of a voltage causes the electric field to be inclined and the liquid crystal to be aligned obliquely. The alignment is restricted by the auxiliary wall structures **96** as well as by the linearly arranged structures **32**, and the liquid crystal inclination propagates to the whole pixels immediately after voltage application, thereby shortening the response time.

FIGS. **124A** to **124E** are views showing a method of fabricating the liquid crystal display apparatus of FIG. **122**. As shown in FIG. **124A**, an ITO **22** is formed on the glass

substrate **14**, thereby forming a film **96**a to constitute band-shaped projections **96**A of the auxiliary wall structures **96**. As shown in FIG. **124**B, the film **96**a for projection is exposed to the ultraviolet ray UV using a mask M, and is developed to form a band-shaped projection **96**A of the auxiliary wall structure **96** (FIG. **124**C). As shown in FIG. **124**D, a film **32**m which is to constitute the linearly arranged structures **32** is formed and, using the mask M, the film **32**m of the linearly arranged structures **32** are exposed to the ultraviolet ray UV and developed to form the linearly arranged structures **32** (FIG. **124**E).

FIGS. **125**A to **125**E are views showing a method of fabricating the liquid crystal display apparatus of FIG. **123**. As shown in FIG. **125**A, the glass substrate **12** is formed with a film **96**b to constitute the band-shaped projection **96**B of the auxiliary wall structures. As shown in FIG. **125**B, using the mask M, the film **96**b for projection is exposed to the ultraviolet ray UV and developed to form the band-shaped projection **96**B of the auxiliary wall structures (FIG. **125**C). As shown in FIG. **125**D, the film of the ITO to constitute the pixel electrodes **22** is formed by vapor deposition, and then as shown in FIG. **125**E, a film to constitute the linearly arranged structures **30** are formed.

FIG. **126** shows an example in which the linearly arranged structures of the lower substrate **14** are slits **46**. The auxiliary wall structures **96** includes conductive projections **96**C formed on the opposite side of the linearly arranged structures **46**. The linearly arranged structures **46** including the slits **46** develop electric lines of force expanding toward the same slit. The electric lines of force develop in the direction expanding toward the slit **46**.

FIG. **127** shows an example in which the linear wall structure of the lower substrate **14** is the slit **46**. The auxiliary wall structures **96**, as in the case of FIG. **122**, includes a band-shaped projection **96** formed under the linearly arranged structures **46**. The linearly arranged structures **46** including the slits **46** develops electric lines of force in the direction expanded toward the slit. The electric lines of force are generated in the direction expanding toward the slit **46**.

FIG. **128** shows an example in which the auxiliary wall structure **96** includes band-shaped projections **96**D, **96**E formed in two stages on the lower substrate **14**. The band-shaped projection **96**D of the lower stage is wider than the band-shaped projection **96**E of the upper stage, and the linearly arranged structures **32** constituting the projections **32** are formed on the band-shaped projections **96**E of the upper stage. In this case, the inclined alignment of the liquid crystal can be restricted by the two side edges of the band-shaped projections **96**D, **96**E formed in two stages. In this configuration, the propagation distance of the alignment inclination of the liquid crystal is one third instead of one half and therefore the response time is improved considerably.

In FIG. **129**, the auxiliary wall structure **96** includes a band-shaped projection **96**F which has a large thickness under the linear wall structure **32** of the lower substrate **14** and inclines outward, progressively decreasing in thickness, away from the linearly arranged structures **32**. Since the band-shaped projection **96**F having a wide area is inclined, the direction of inclined alignment of the liquid crystal can be restricted by the difference of the shape and the specific dielectric constant over a wide area. Further, the light leakage, which is caused by the shape of the edge, when no voltage is applied can be reduced. The inclined structure can be formed by the reflow of a photosensitive material.

FIG. **130** shows an example in which a corrugated projection **98** is formed on the lower substrate **14**, and this projection **98** is caused to function as the linearly arranged structures **32** and the auxiliary wall structure **96**. The period of the corrugation is changed, and the parameter changing in one direction is the period of corrugation. When the period of corrugation is long, the average force of restricting the inclined alignment of the liquid crystal weakens. Further, the average electric field distribution is inclined. Thus, the liquid crystal can be aligned by inclination. In this way, the inclined alignment of the liquid crystal can be restricted in a wide area.

FIG. **131** shows an example in which a projection **97** changed in dielectric constant is formed on the lower substrate **14**, and this projection **97** is caused to function as the linearly arranged structures **32** and the auxiliary wall structure **96**. The projection **97** includes a portion where the specific dielectric constant is decreased from $\epsilon 1$ to $\epsilon 2$ to $\epsilon 3$ in steps. Since the electric field inclination occurs in the area where the specific dielectric constant changes, the inclined alignment of the liquid crystal can be restricted. The relative dielectric constant of the projection **97** may be changed continuously.

FIG. **132** shows an embodiment in which the pixel electrode **22** is configured of a conductor **99**A of low resistivity and a conductor **99**B of high resistivity. The conductor **99**A of low resistivity is narrower than the conductor **99**B of high resistivity. The conductor **99**A of low resistivity is covered by the conductor **99**B of high resistivity and located at the center of the conductor **99**B of high resistivity. As a result, an electric field inclination is developed as the charge spreads from the conductor **99**B in time due to the time constant determined by the electrostatic capacity of the electrode **18** on the opposed substrate and the conductor **99**B of high resistivity. Thus, the inclined alignment of the liquid crystal can be restricted.

FIGS. **133**A to **133**C are views showing an embodiment in which an unevenness is formed at the end of the projection as the auxiliary wall structure **96**. In FIG. **133**A, the projection end is formed in a triangular wave **96**H as the auxiliary wall structure **96**. In FIG. **133**B, the projection ends are formed as a curve **961** as the auxiliary wall structure **96**. In FIG. **133**C, the projection ends are formed as a rectangular wave **96**J as the auxiliary wall structure **96**. By forming an unevenness at the end of the projection, the orientation of the liquid crystal can be stabilized. When the liquid crystal is aligned obliquely, the alignment tends to be parallel to the projection. In the auxiliary wall structure **96**, the liquid crystal is required to be aligned in the direction perpendicular to the projection. In the case where the projection ends are uneven, the forces tending to align the projections in a position parallel to the projection offset each other, with the result that the liquid crystal is oriented in the direction perpendicular to the projection.

FIGS. **134**A to FIG. **134**C are views showing an embodiment in which the section of the projection is defined as the auxiliary wall structure **96**. In FIG. **134**A, the section of the projection as the auxiliary wall structure **96** is trapezoidal **96**K in shape. In FIG. **134**B, the section of the projection as the auxiliary wall structure **96** is arcuate **96**L in shape. In FIG. **134**C, the section of the projection as the auxiliary wall structure **96** is curved **96**M in shape. By doing so, the area for defining the inclined orientation of the liquid crystal can be widened. Further, a steep section geometrically disturbs the liquid crystal orientation when no voltage is applied thereto. A smooth sectional shape can reduce the light leakage caused by the orientation defect of the edge.

A further embodiment can be configured from the embodiments explained with reference to FIGS. **122** to **134**. For example, in the above-mentioned embodiments, the structure of restricting the inclined orientation of the liquid crystal is formed only on one substrate. Instead, the structure for restricting the inclined alignment of the liquid crystal can be formed on the two substrates. Then, a comparatively uniform cell thickness in the pixel can be secured thereby providing a uniform optical characteristic. Further, the force for restricting the inclined orientation of the liquid crystal is increased.

Also, when the liquid crystal is driven by the TFT, the process for projection fabrication can be simplified by forming the projection of a gate insulating film or the last protective film of silicon nitride or the like. Addition of a chiral material to the liquid crystal can shorten the response time of the liquid crystal for a small electric field. The twist energy of the liquid crystal can restore the liquid crystal alignment more rapidly.

As described above, the means (auxiliary wall structure) for restricting the inclined alignment of a second liquid crystal, which increases or reduces the parameter in one direction from the linearly arranged structures, is formed between the linearly arranged structures. Thus, the direction in which the liquid crystal orientation is inclined can be restricted. As a result, the propagation rate of the direction of inclination of the liquid crystal alignment increases during the transition from black to white display, and therefore the response time can be shortened, thereby greatly contributing to the display performance of the display apparatus involved.

As described above, according to the present invention, a liquid crystal display apparatus can be fabricated which is improved in brightness and higher in response speed. The direction of orientation of all the domains formed on the linear wall structure can be determined and the age-based variation of the domains can be suppressed, thereby improving the overshoot.

What is claimed is:

1. A liquid crystal display apparatus comprising:

a pair of substrates having electrodes and vertical alignment layers;

a liquid crystal having a negative anisotropy of dielectric constant and inserted between said pair of substrates;

alignment control structures arranged in each of said pair of substrates for controlling alignment of the liquid crystal;

each of said alignment control structures comprising a plurality of constituent units; and

the constituent units of one substrate being arranged on a first line, the constituent units of the other substrate being arranged on a second line, said first line overlapping said second line, the constituent units of one substrate arranged on said first line and the constituent units of the other substrate on said second line being arranged alternately as viewed in a normal direction to the substrates.

2. A liquid crystal display apparatus as described in claim **1**, characterized in that the alignment control structures comprise linearly arranged structures, and the constituent units of the linearly arranged structures of one substrate and the constituent units of the linear wall structures of the other substrate are arranged alternately with one pixel.

3. A liquid crystal display apparatus as described in claim **1**, characterized in that the alignment control structures comprise linearly arranged structures, and each linearly arranged structure has a plurality of constituent units in one pixel, and the linearly arranged structures are arranged substantially symmetrically in one pixel.

4. A liquid crystal display apparatus as described in claim **1**, characterized in that said means for forming boundary of alignment comprise partial transverse enlargement of the width of the alignment control structures.

5. A liquid crystal display apparatus comprising:

a pair of substrates having electrodes and vertical alignment layers;

a liquid crystal having a negative anisotropy of dielectric constant and inserted between said pair of substrates;

alignment control structures arranged in each of said pair of substrates for controlling the liquid crystal; and

auxiliary structures formed on at least one of said pair of substrates between the alignment control structures of said pair of substrates as viewed in the direction normal to said pair of substrates.

6. A liquid crystal display apparatus as described in claim **5**, characterized in said alignment control structures comprise linearly arranged structures, and that said auxiliary structures are arranged at predetermined pitches along the linearly arranged structures.

7. A liquid crystal display apparatus as described in claim **5**, characterized in that said auxiliary structures have a shape long in the direction perpendicular to the linearly arranged structures.

8. A liquid crystal display apparatus comprising:

a pair of substrates having electrodes and vertical alignment layers;

a liquid crystal having a negative anisotropy of dielectric constant and inserted between said pair of substrates;

alignment control structures arranged in each of said pair of substrates for controlling alignment of the liquid crystal; and

liquid crystal inclined alignment control means arranged between the alignment control substrate of said pair of substrates in which a parameter changes in one direction from one of the alignment control structures.

9. A liquid crystal display apparatus as described in claim **8**, characterized in that said parameter includes at least one of a height of the linearly arranged structures, a period of the linearly arranged structures, a dielectric constant of the linearly arranged structures and accumulated value of a time constant due to a resistor and a capacitor of a pixel electrode.

* * * * *

EXHIBIT B

US006952192B2

(12) **United States Patent**
Ohmuro et al.

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(45) **Date of Patent: Oct. 4, 2005**

(54) **LIQUID CRYSTAL DISPLAY DEVICE AND ITS DRIVE METHOD**

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(57) **ABSTRACT**

A MVA type liquid crystal panel is slow in a response speed when a black state at a drive voltage about 1V is switched to a low brightness halftone state at the drive voltage about 2 to 3V. According to the present invention, in a liquid crystal display device for driving the MVA type liquid crystal panel, when a liquid crystal pixel at a pixel electrode is changed from a first transmittance to a second transmittance greater than the first transmittance, a drive voltage greater than a first target drive voltage in correspondence with a second transmittance is applied to the pixel electrode in a first frame period of changing to the second transmittance, and the first target display voltage is applied from a second frame period. According to the present invention, even when either switching is performed from a black state to a low brightness halftone state, from the black state to a high brightness halftone state, or from the black state to a white state, a response time is shortened, and the switching can be performed without generating an overshoot.

4 Claims, 21 Drawing Sheets

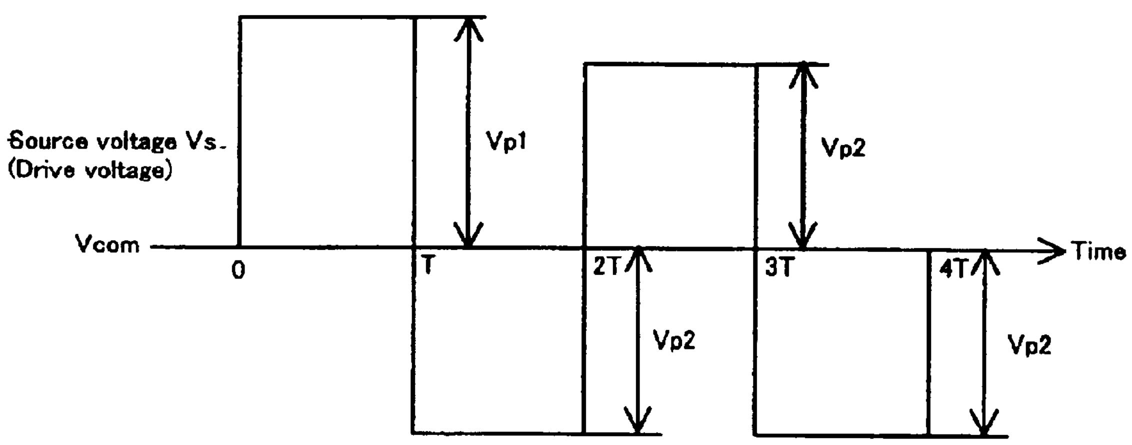


FIG. 1

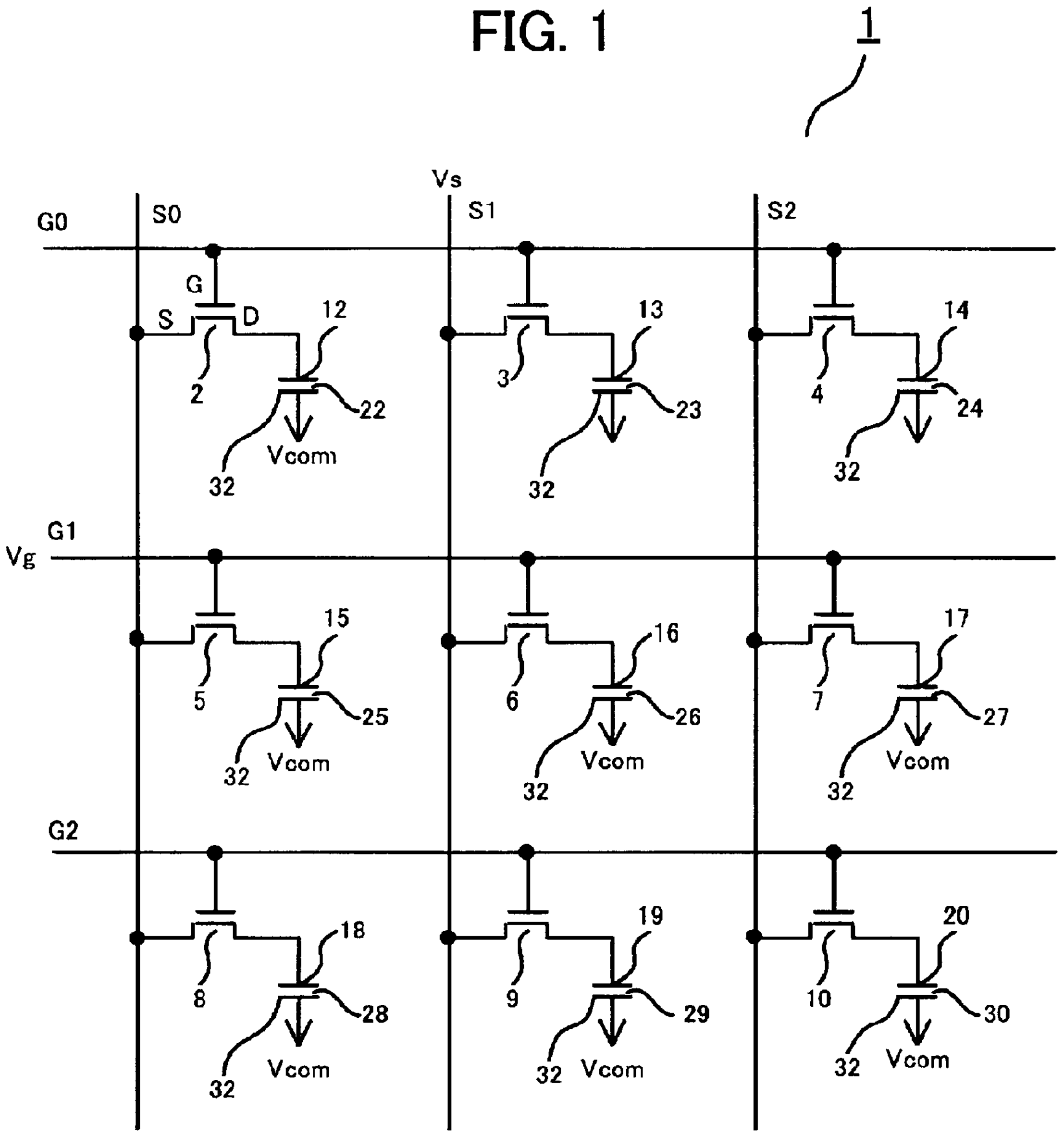

1
Vs
G0
S0
S1
S2
G
S
D
12
13
14
2
3
4
22
23
24
Vcom
32
G1
Vg
15
16
17
5
6
7
25
26
27
G2
18
19
20
8
9
10
28
29
30

FIG. 2A

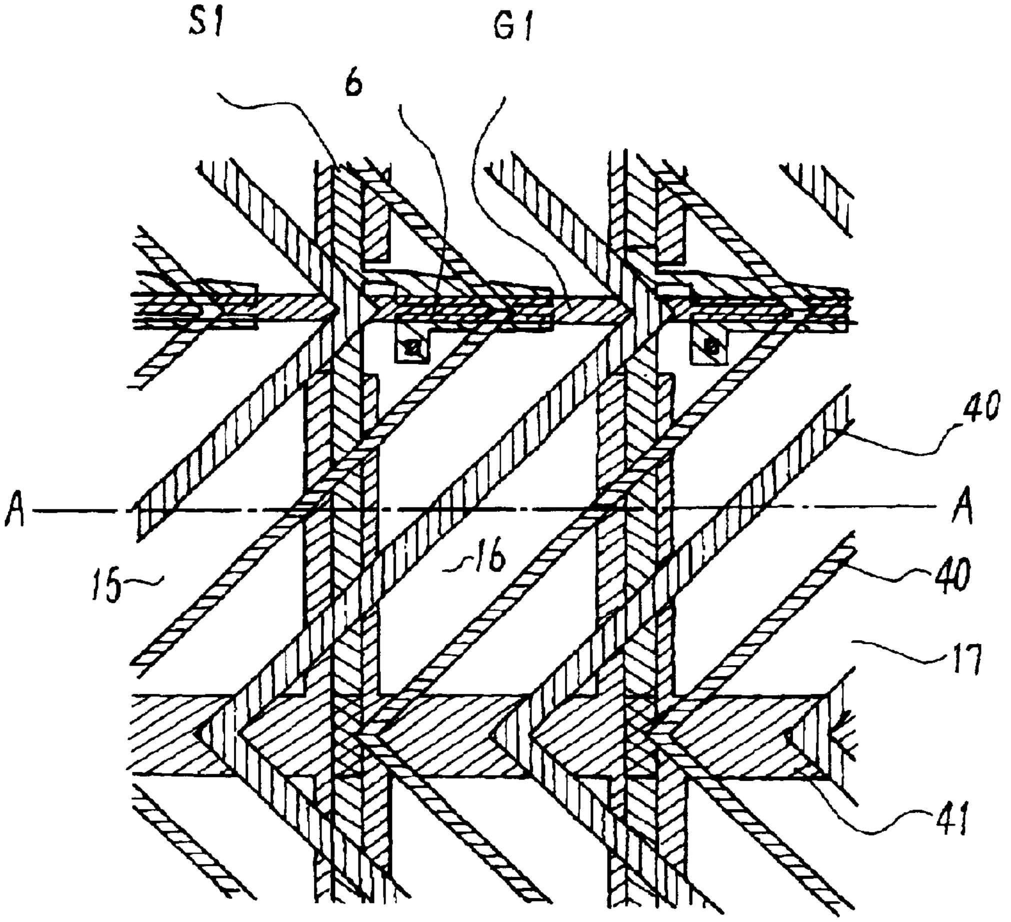


FIG. 2B

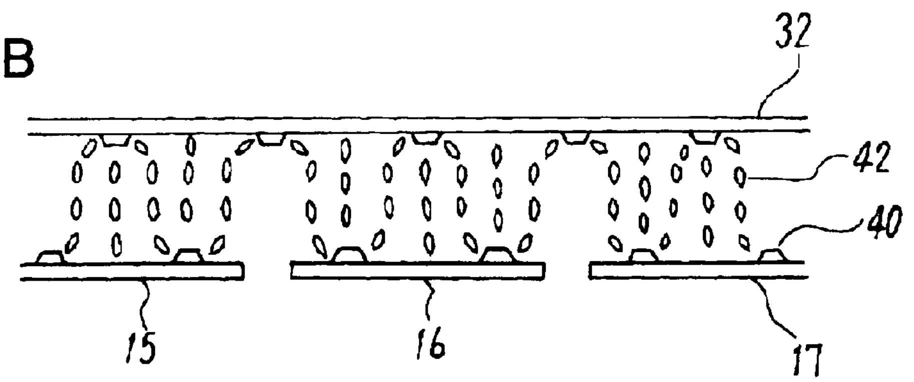


FIG. 3A

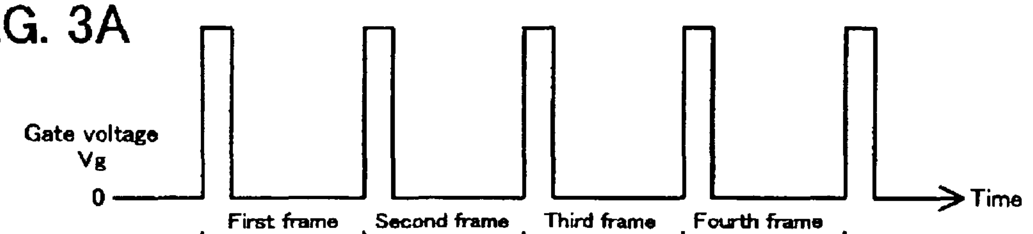


FIG. 3B
PRIOR ART

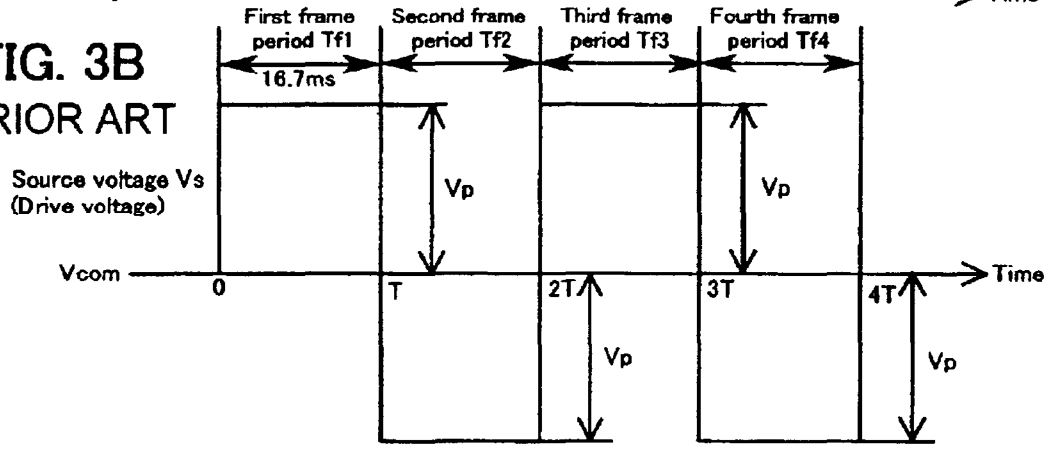


FIG. 3C

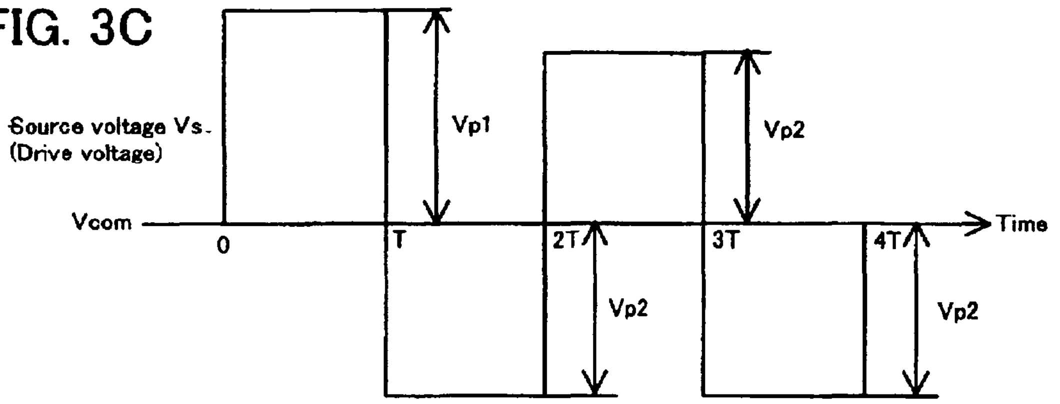
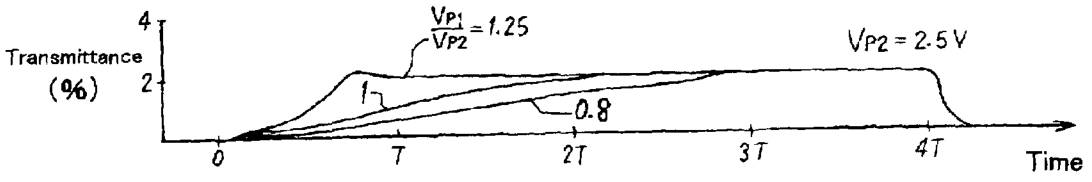
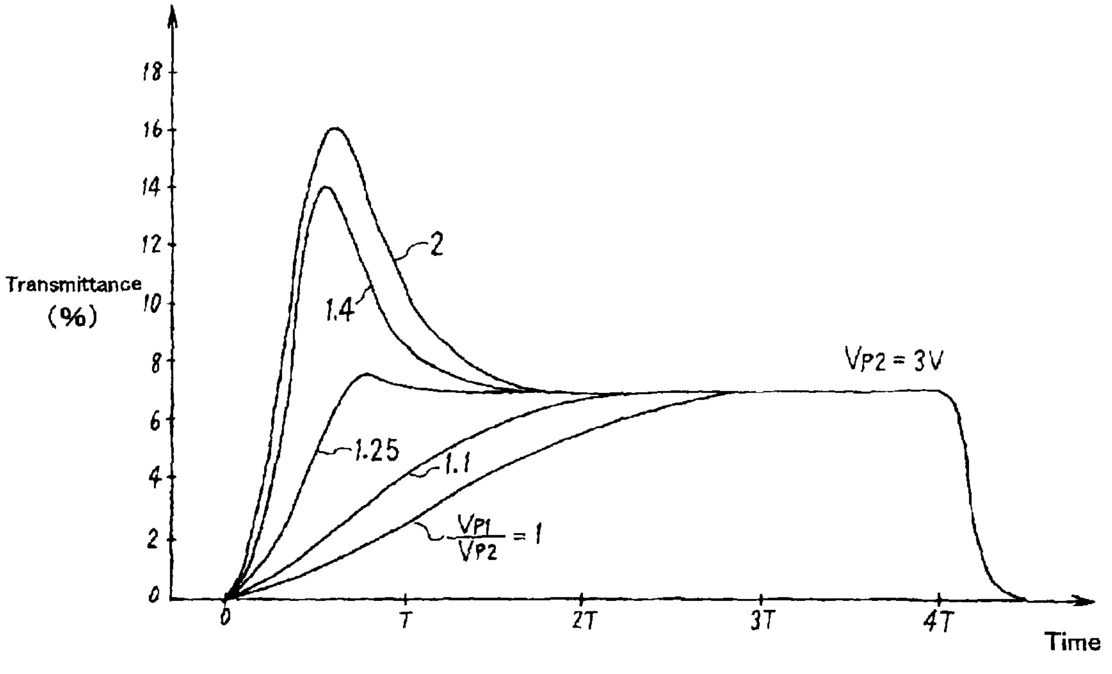


FIG. 4A



4
Transmittance
(%)
2
$\frac{V_{P1}}{V_{P2}} = 1.25$
1
0.8
$V_{P2} = 2.5V$
0
T
2T
3T
4T
Time

FIG. 4B



18
16
14
12
Transmittance
(%)
10
8
6
4
2
0
2
1.4
1.25
1.1
$\frac{V_{P1}}{V_{P2}} = 1$
$V_{P2} = 3V$
T
2T
3T
4T
Time

FIG. 5A

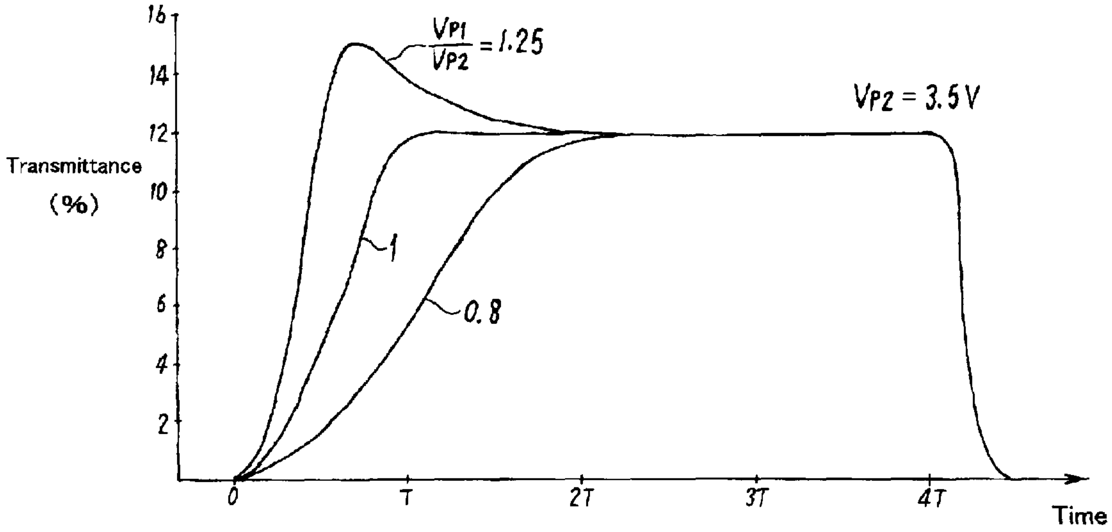

16
14
12
10
8
6
4
2
Transmittance (%)
$\frac{Vp1}{Vp2}$ = 1.25
Vp2 = 3.5 V
1
0.8
0
T
2T
3T
4T
Time

FIG. 5B

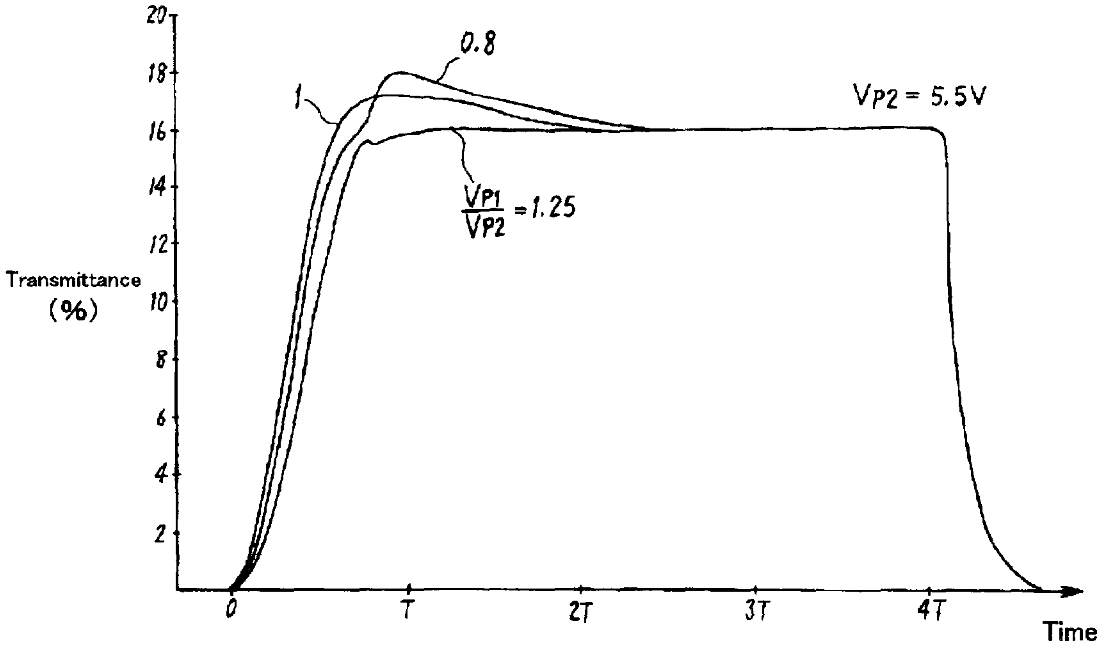

20
18
16
14
12
10
8
6
4
2
Transmittance (%)
0.8
1
Vp2 = 5.5V
$\frac{Vp1}{Vp2}$ = 1.25
0
T
2T
3T
4T
Time

FIG. 6A

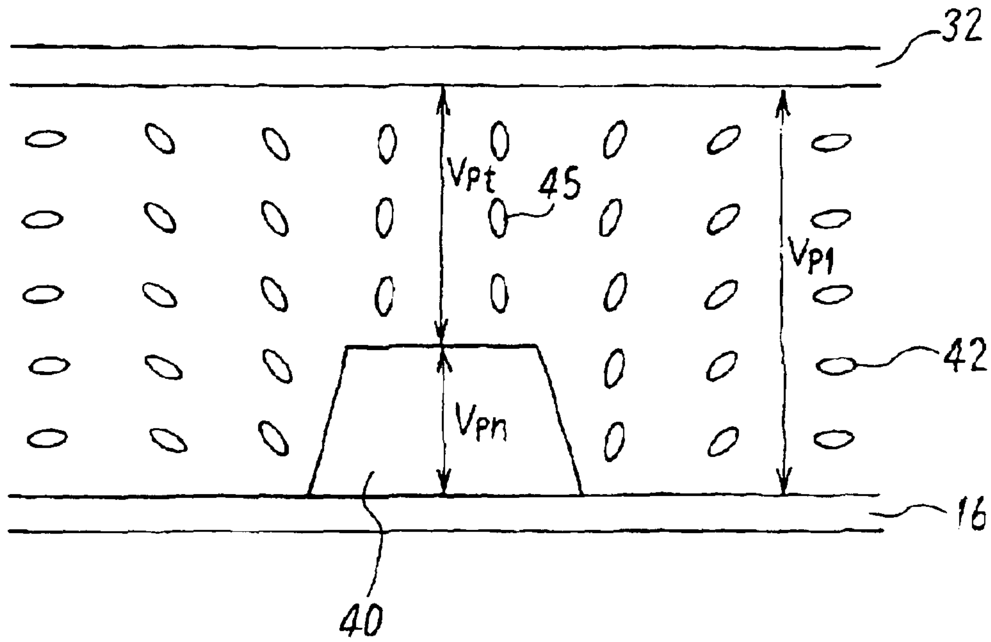


FIG. 6B

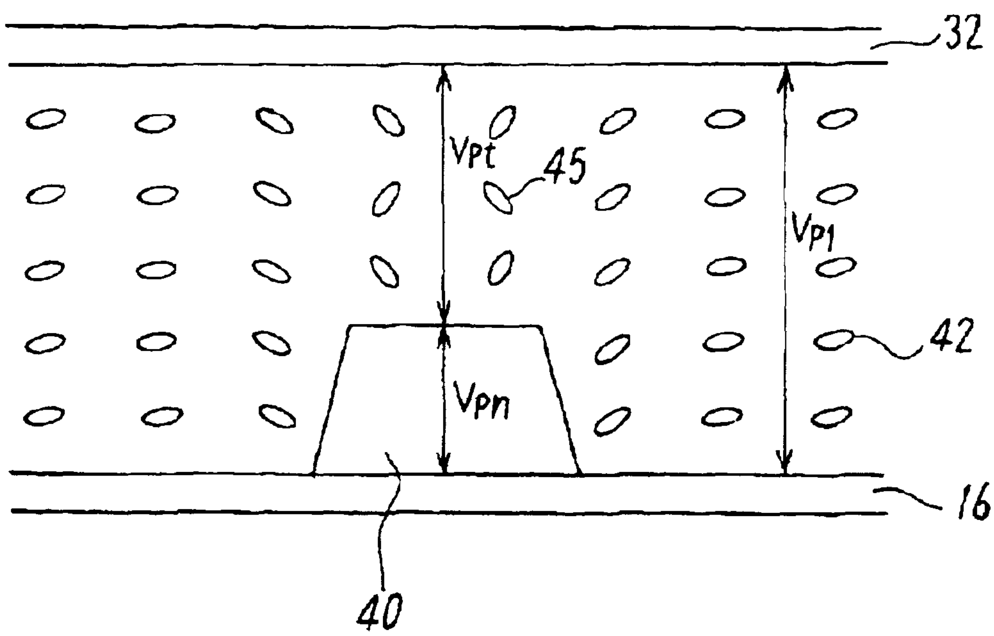
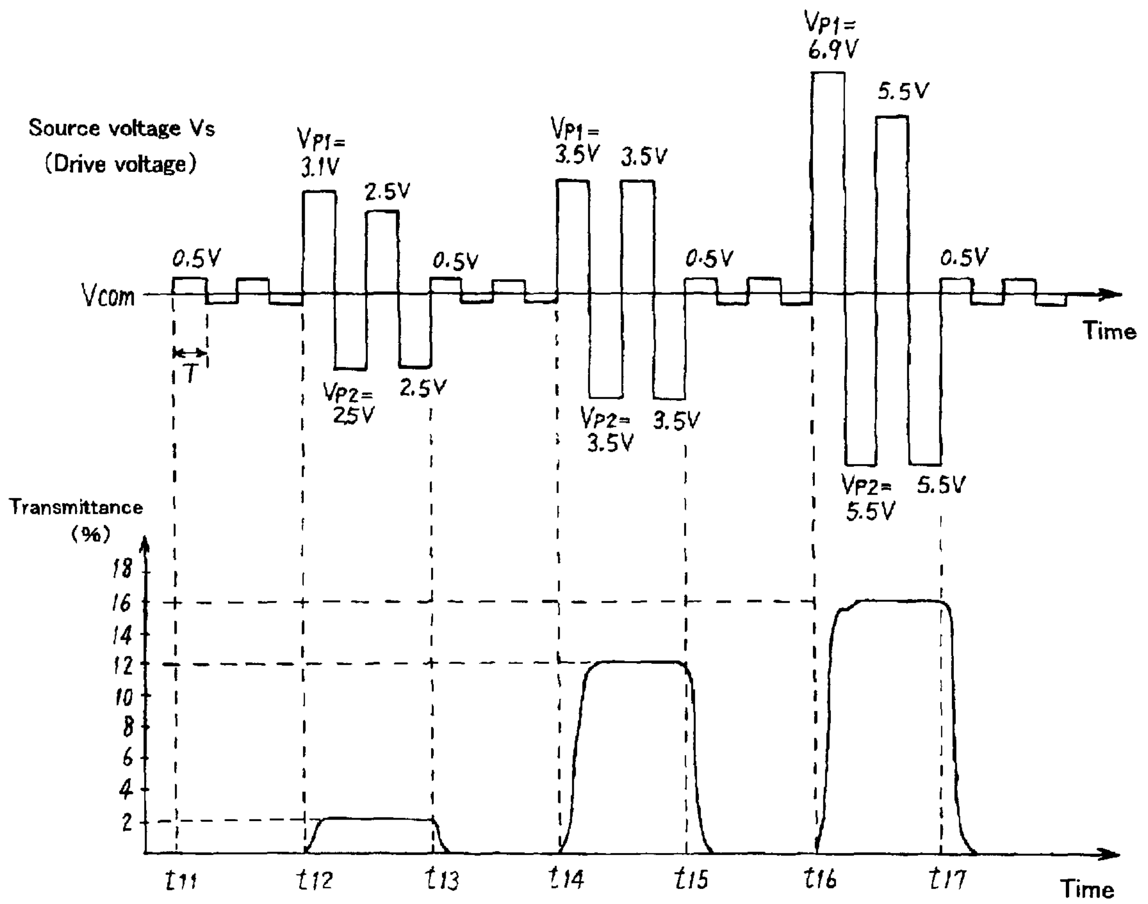


FIG. 7



Source voltage Vs
(Drive voltage)
0.5V
Vcom
T
Vp1= 3.1V
2.5V
Vp2= 2.5V
2.5V
0.5V
Vp1= 3.5V
3.5V
Vp2= 3.5V
3.5V
0.5V
Vp1= 6.9V
5.5V
Vp2= 5.5V
5.5V
0.5V
Time
Transmittance (%)
18
16
14
12
10
8
6
4
2
t11
t12
t13
t14
t15
t16
t17
Time

FIG. 8

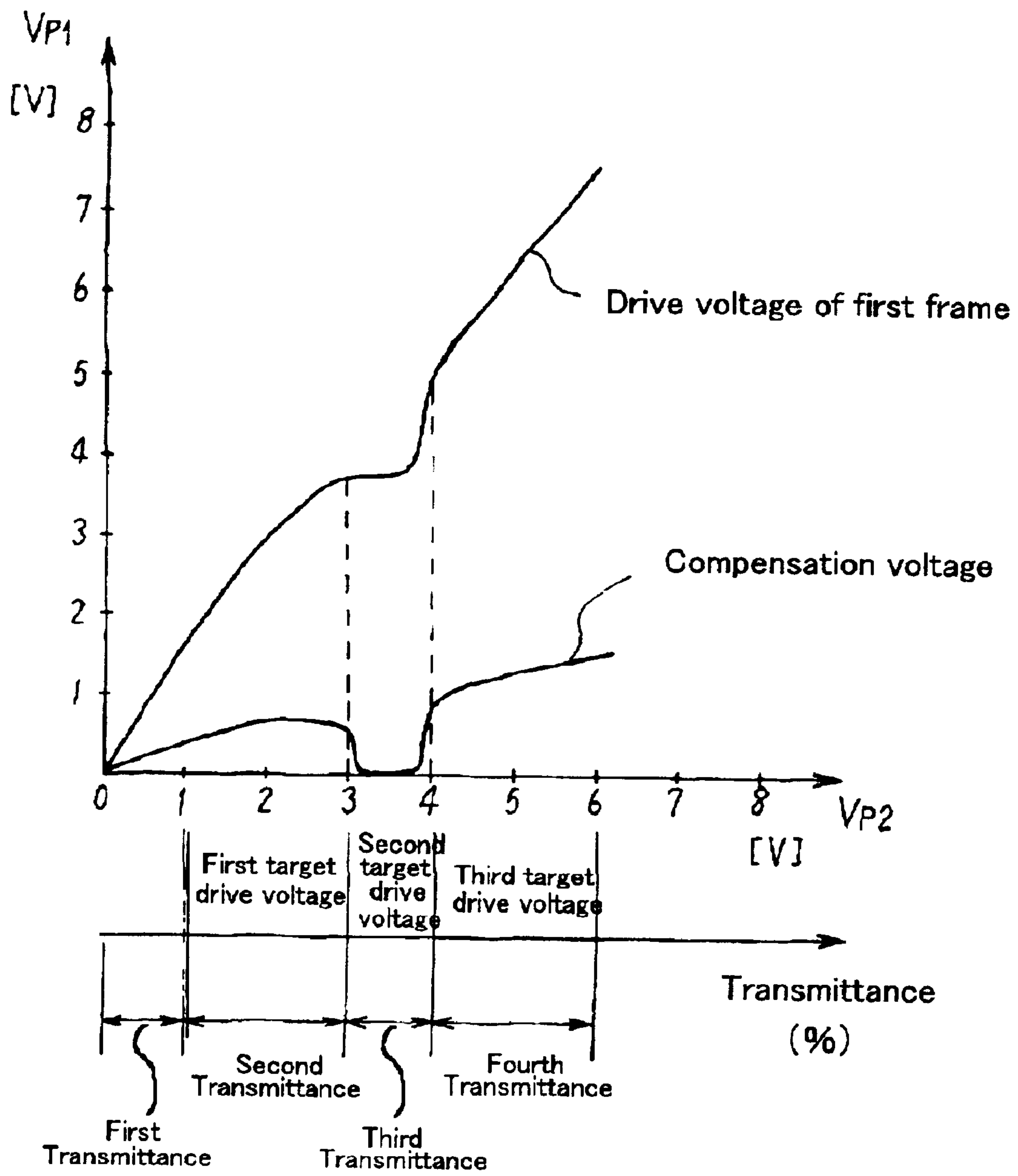
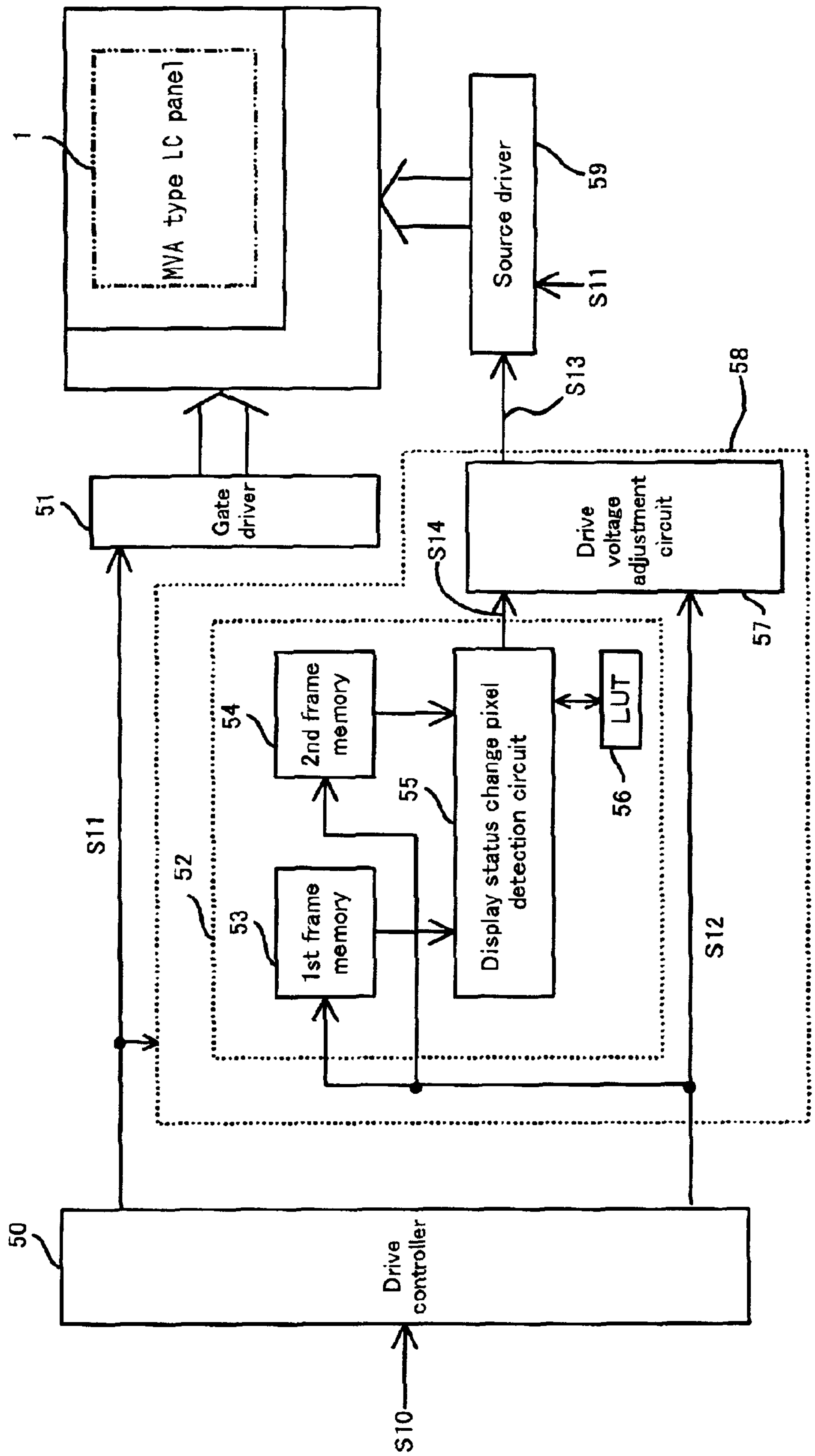

Vp1
[V]
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
Vp2
[V]
Drive voltage of first frame
Compensation voltage
First target drive voltage
Second target drive voltage
Third target drive voltage
Transmittance
(%)
First Transmittance
Second Transmittance
Third Transmittance
Fourth Transmittance

FIG. 9



MVA type LC panel
1
Source driver
59
S11
S13
58
Gate driver
51
Drive voltage adjustment circuit
S14
57
2nd frame memory
54
Display status change pixel detection circuit
55
LUT
56
1st frame memory
53
52
S11
S12
Drive controller
50
S10

FIG. 10

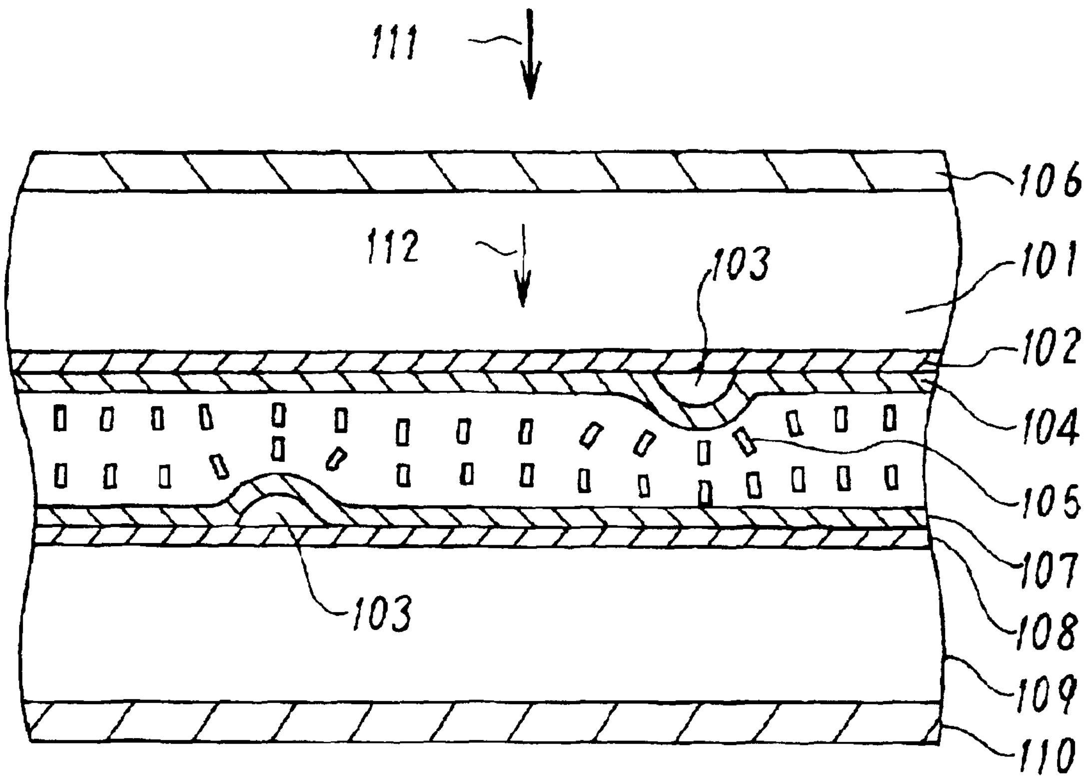


FIG. 11A

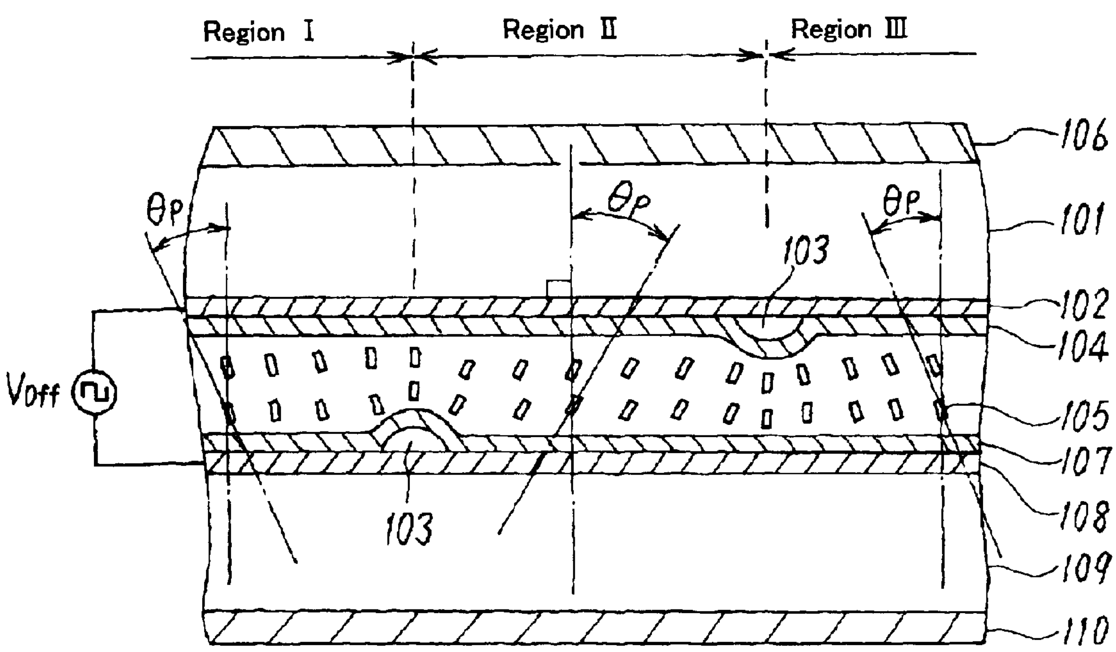


FIG. 11B

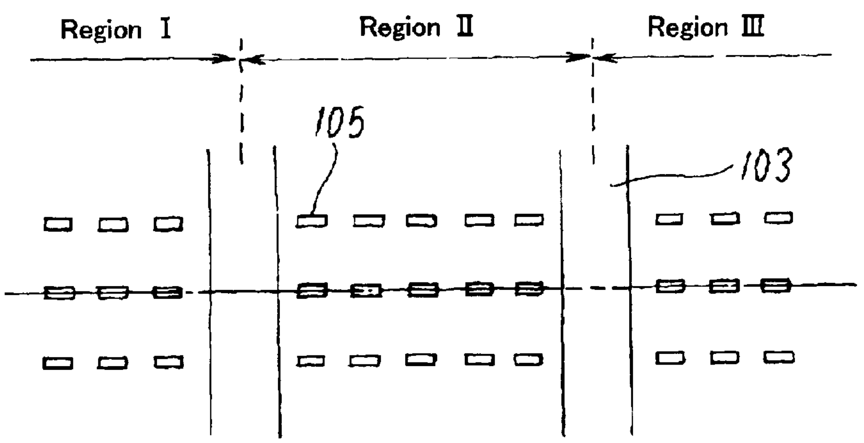


FIG. 12

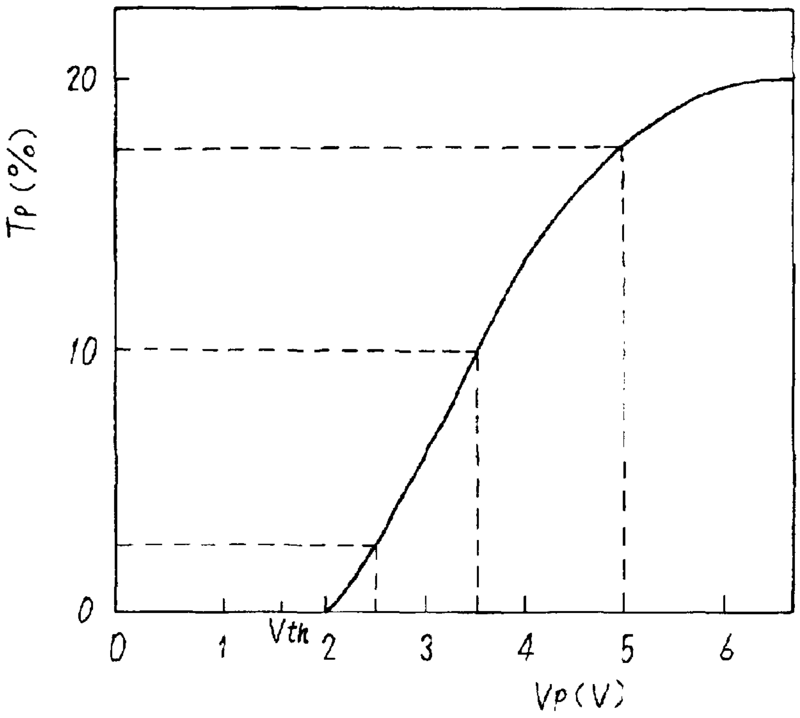


FIG. 13

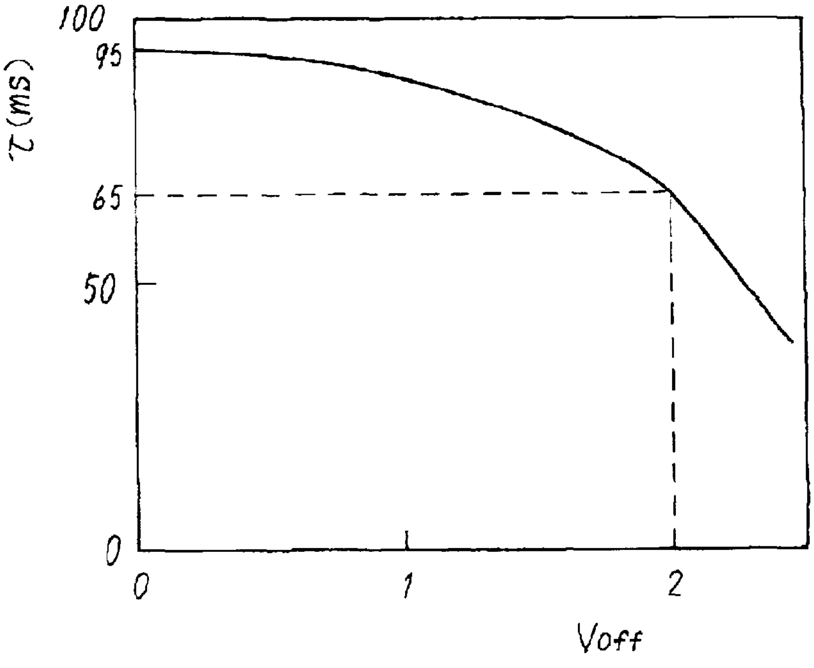


FIG. 14

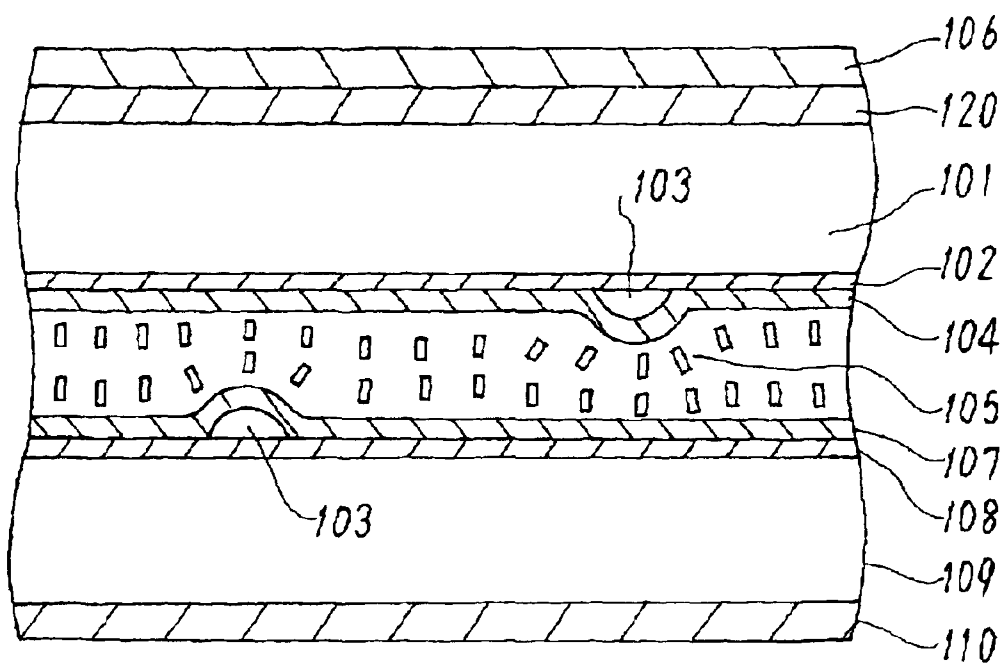


FIG. 15

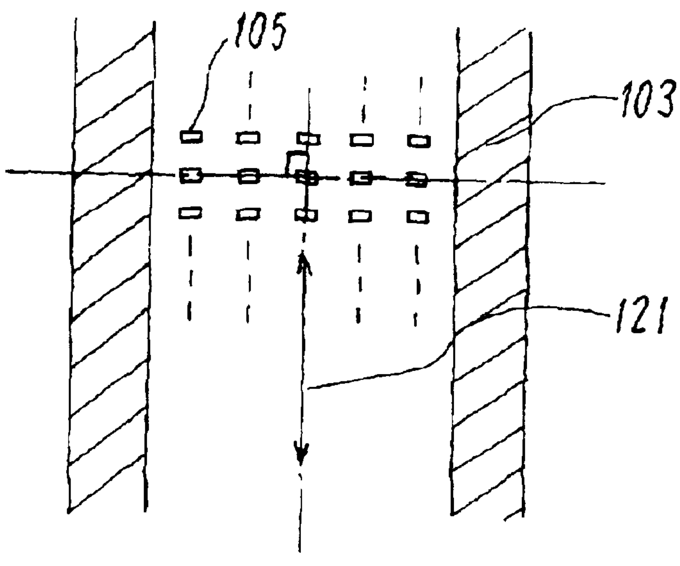
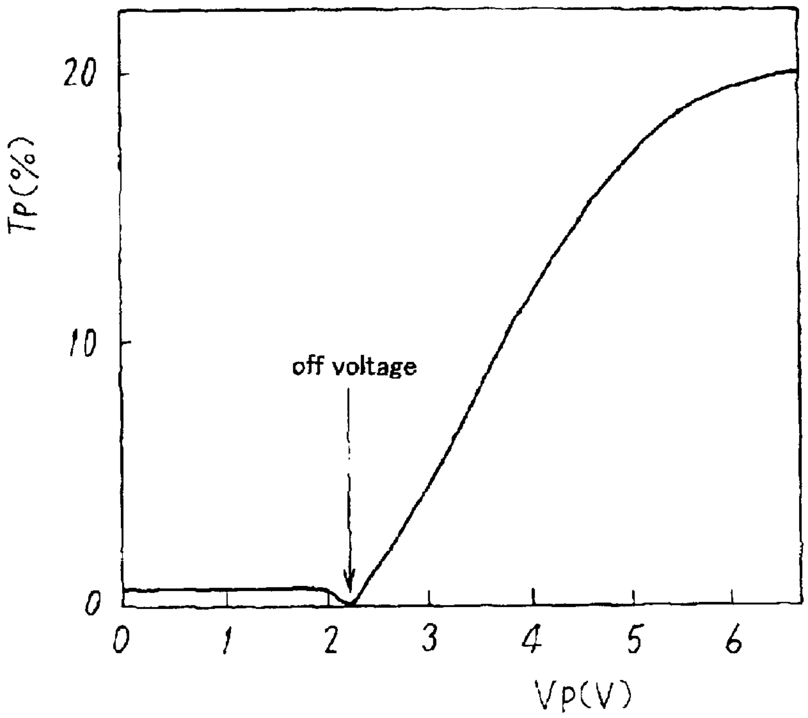
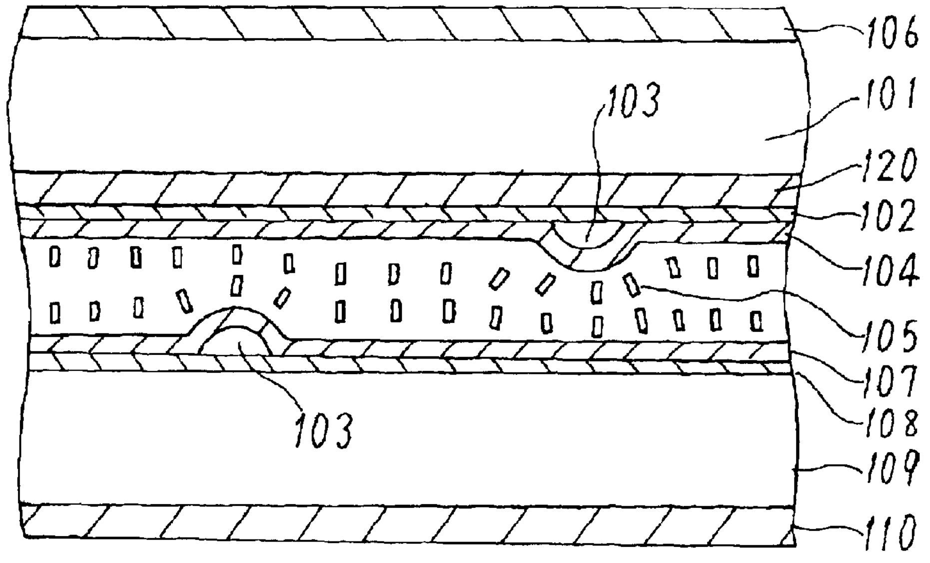


FIG. 16



Tp(%)
20
10
0
off voltage
0
1
2
3
4
5
6
Vp(V)

FIG. 17



106
101
103
120
102
104
105
107
108
109
110
103

FIG. 18

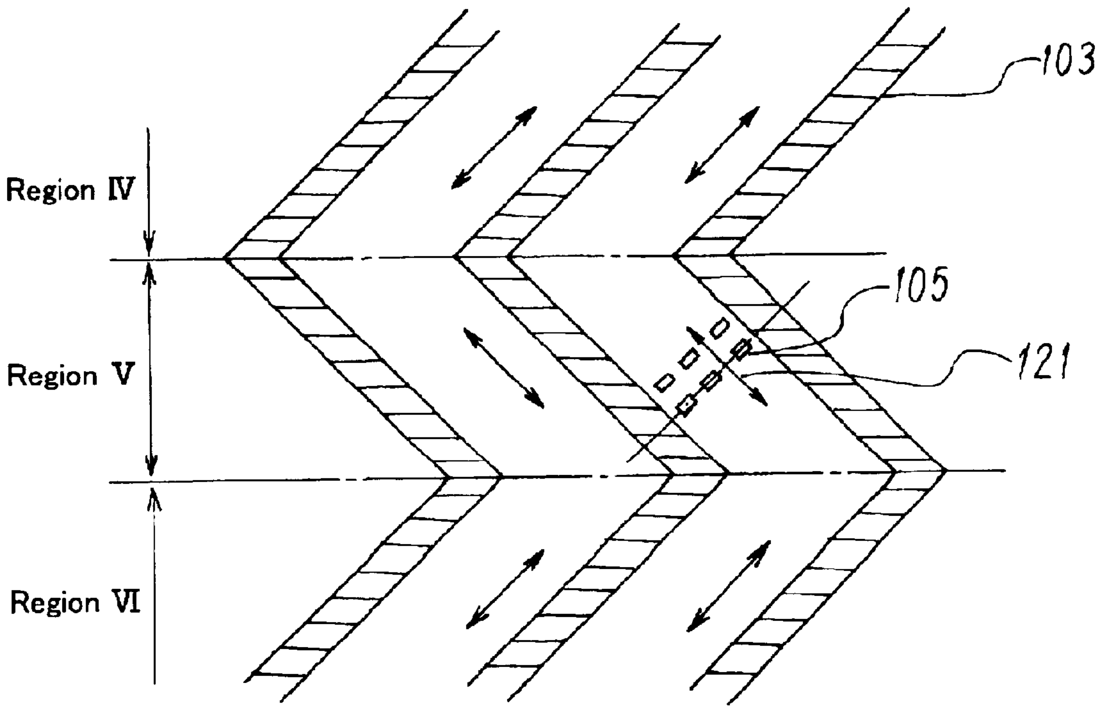


FIG. 19

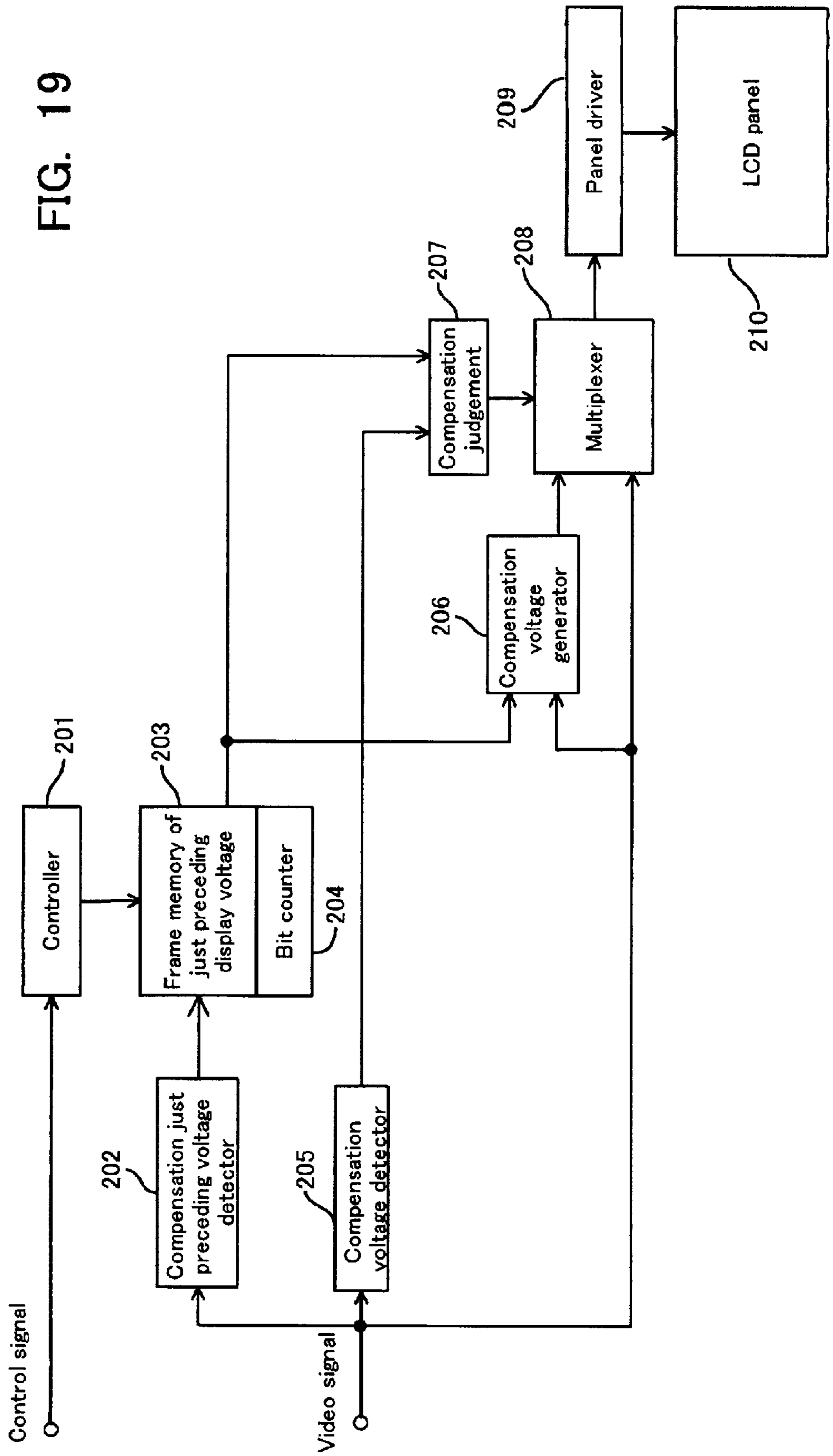

Control signal
Video signal
Controller
201
Frame memory of just preceding display voltage
203
Bit counter
204
Compensation just preceding voltage detector
202
Compensation voltage detector
205
Compensation voltage generator
206
Compensation judgement
207
Multiplexer
208
Panel driver
209
LCD panel
210

FIG. 20A No Compensation

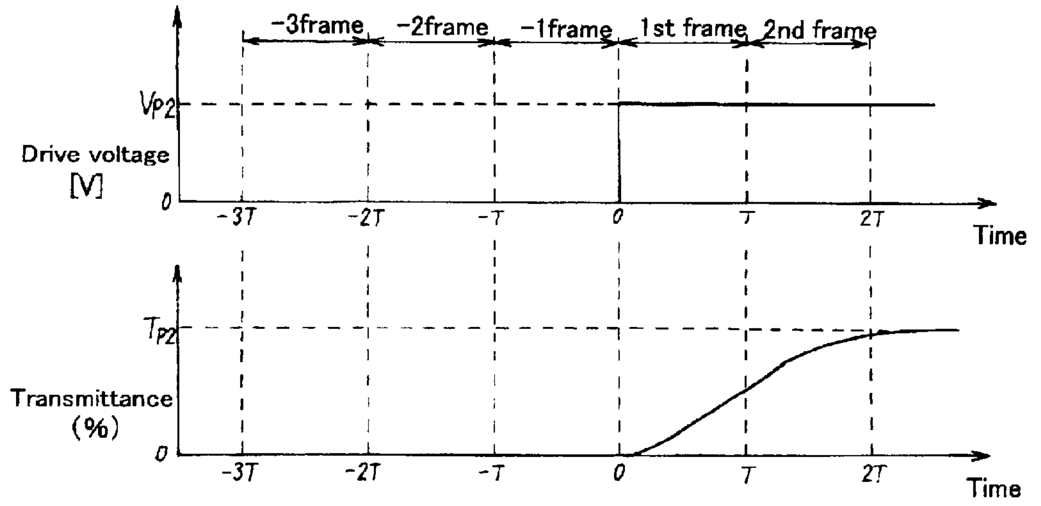


FIG. 20B

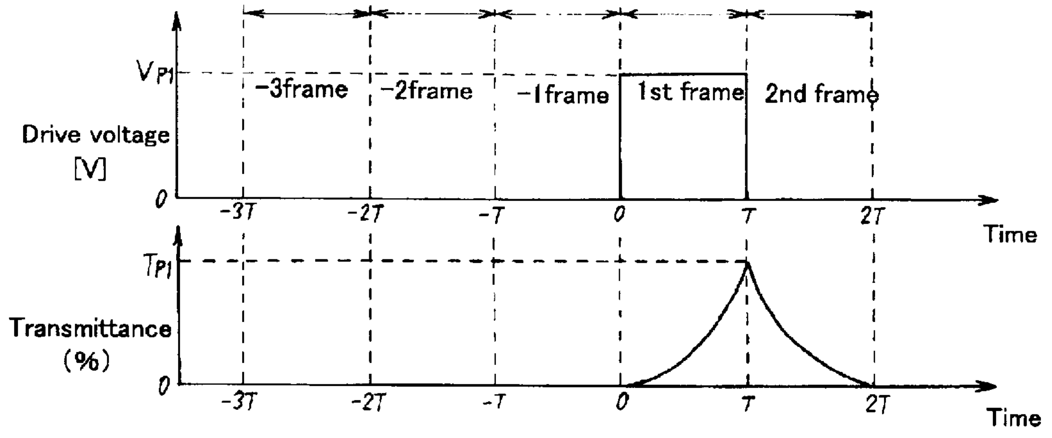


FIG. 20C With Compensation

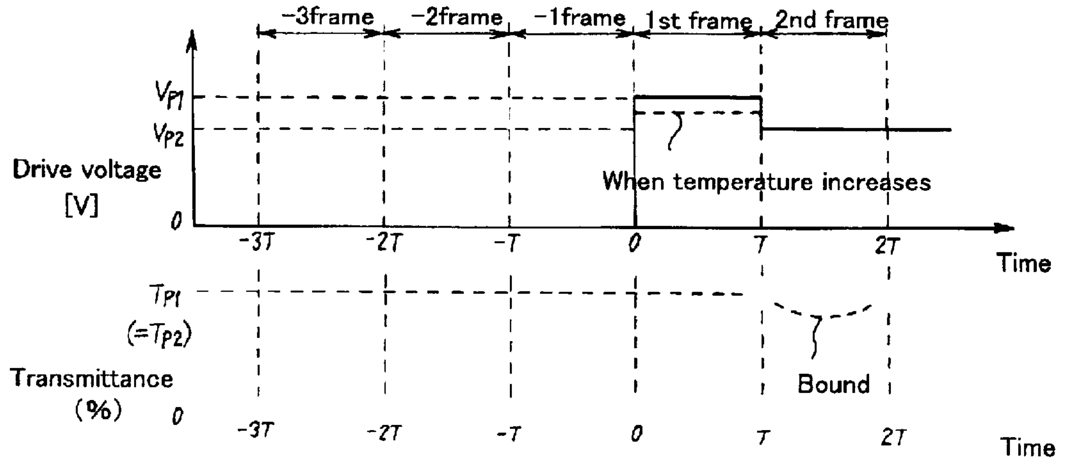
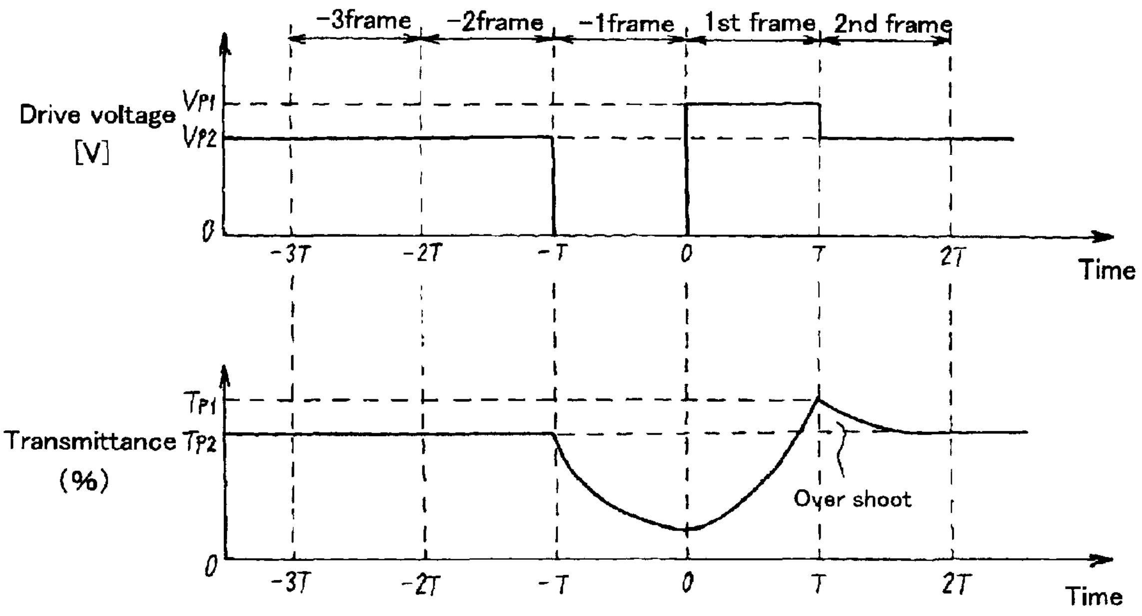


FIG. 21



−3frame
−2frame
−1frame
1st frame
2nd frame
Drive voltage
[V]
VP1
VP2
0
-3T
-2T
-T
0
T
2T
Time
TP1
Transmittance TP2
(%)
Over shoot
0
-3T
-2T
-T
0
T
2T
Time

FIG. 22

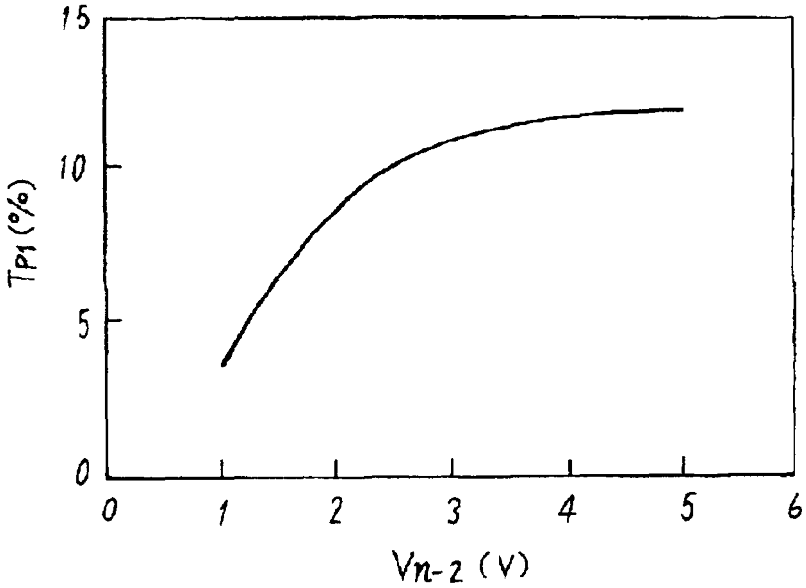


FIG. 23

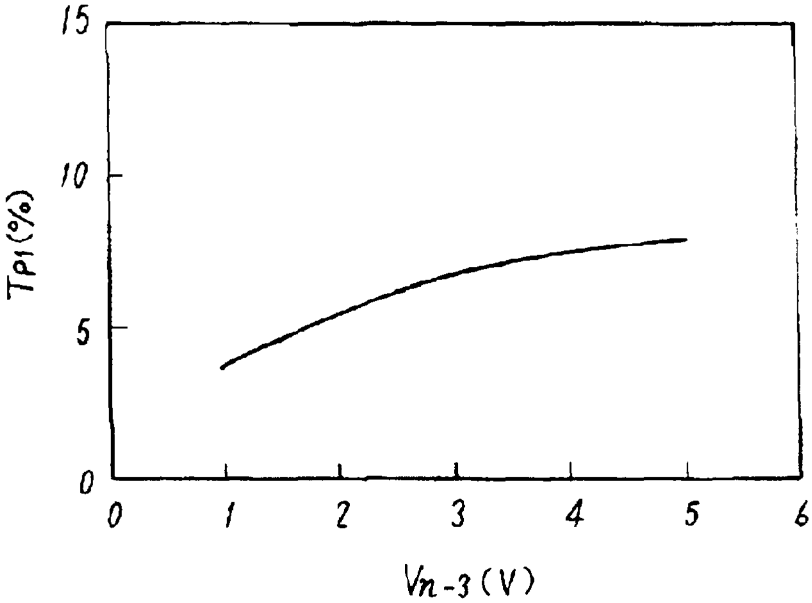
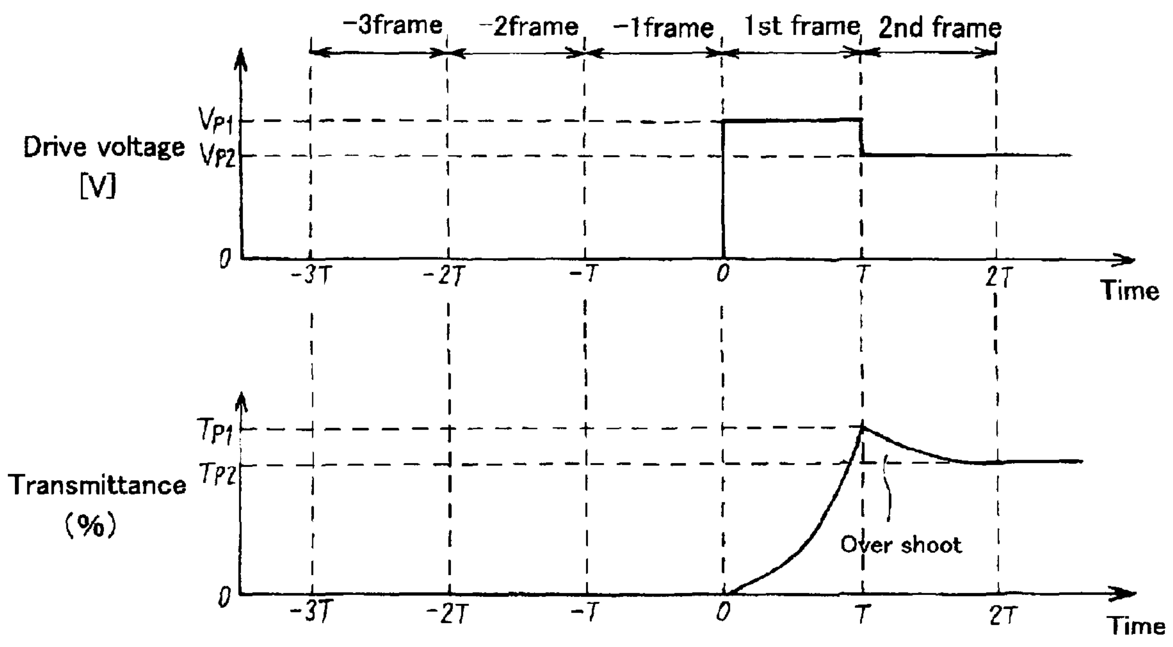


FIG. 24



−3frame
−2frame
−1frame
1st frame
2nd frame
Drive voltage [V]
VP1
VP2
0
-3T
-2T
-T
0
T
2T
Time
Transmittance (%)
TP1
TP2
Over shoot
0
-3T
-2T
-T
0
T
2T
Time

FIG. 25

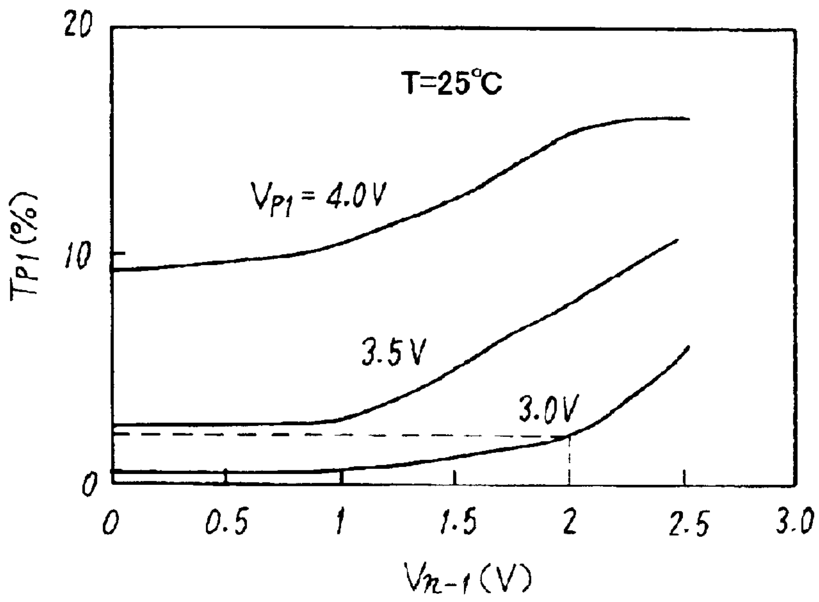
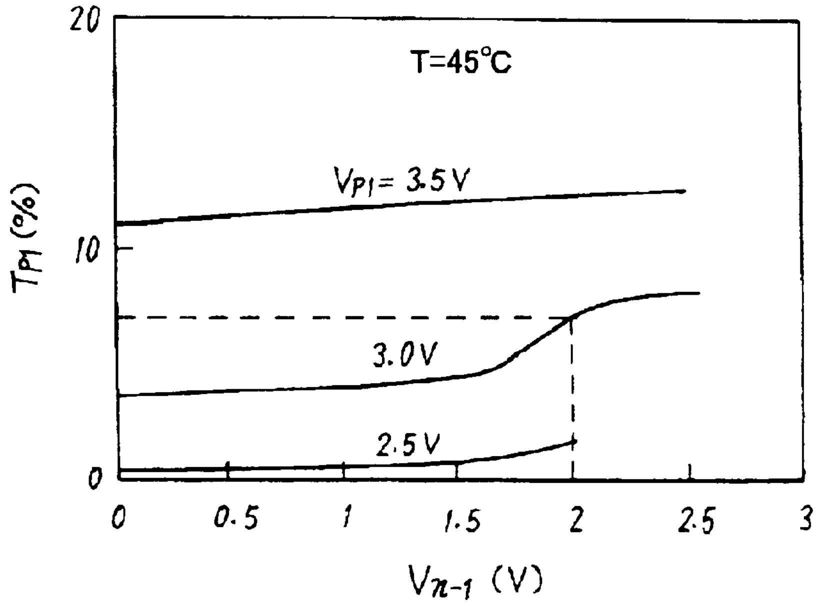

20
T=25°C
Vp1 = 4.0V
10
3.5V
3.0V
0
0.5
1
1.5
2
2.5
3.0
Tp1 (%)
Vn-1 (V)

FIG. 26


20
T=45°C
Vp1= 3.5V
10
3.0V
2.5V
0
0.5
1
1.5
2
2.5
3
Tp1 (%)
Vn-1 (V)

LIQUID CRYSTAL DISPLAY DEVICE AND ITS DRIVE METHOD

CROSS REFERENCE TO RELATED APPLICATION

The present application is a continuation of International Application number PCT/JP99/06189, filed Nov. 5, 1999, the entire contents of which are herein incorporated by the reference.

TECHNICAL FIELD

The present invention relates to a liquid crystal display device and its drive method, and in particular to the liquid crystal display device in which a liquid crystal having minus dielectric constant anisotropy is aligned vertically when non-voltage is applied; and its drive method.

BACKGROUND ART

At present, in a liquid crystal panel which carries out active matrix drive by use of a thin film transistor (hereinafter called TFT), its mainstream is a TN (Twisted Nematic) mode liquid crystal panel in which a p type liquid crystal having positive dielectric anisotropy is aligned horizontally to a substrate when non-voltage is applied, and is driven vertically to the substrate when voltage is applied.

With the progress of late manufacturing technology, the TN mode liquid crystal panel has been improved conspicuously in contrast, a gradation characteristic, and color reproducibility seen from the facade of the liquid crystal panel. However, the TN mode liquid crystal mode has drawbacks that a viewing angle is narrower than CRT, etc., and for this reason there is a problem that the use is restricted.

For the purpose of improving the drawback of the TN mode liquid crystal panel that the viewing angle is narrow, we, the applicant of this invention, developed a MVA (Multidomain Vertical Alignment) type liquid crystal panel which drives horizontally, when voltage is applied, liquid crystal molecules aligned vertically when non-voltage is applied, and in which an alignment direction of the liquid crystal molecules in one pixel is divided into a plurality of parts, and disclosed the structure in Japanese Patent Application Laid-Open No. 10-185836, etc.

The MVA type liquid crystal panel uses an n type liquid crystal having negative dielectric anisotropy and the MVA type liquid crystal panel is provided with domain restriction means for, when voltage is applied, restricting an alignment direction of the liquid crystal so that the direction is set to be a plurality of parts in one pixel.

The domain restriction means incline in advance the liquid crystal molecules at a projection part at a slight angle when non-voltage is applied, by the projection, etc. provided in a part on an electrode. This projection performs a role of a trigger for determining the alignment direction of the liquid crystal molecules when voltage is applied, and any small projection is enough. Incidentally, as the MVA type liquid crystal panel inclines in advance the liquid crystal molecules at a slight angle by the domain restriction means, a rubbing process to a vertical alignment layer or alignment film is unnecessary.

In the MVA type liquid crystal, in a state that non-voltage is applied, most of liquid crystal molecules are aligned vertically to a surface of the substrate, and the transmittance becomes a status of 0 (black state). When an intermediate voltage is applied, the inclination direction of the liquid crystal molecules is determined under the influence of an

inclined plane of the projection, and the alignment direction of the liquid crystal in one pixel is partitioned. Accordingly, the intermediate voltage causes an optical characteristic of the liquid crystal in one pixel to average, thereby obtaining a halftone state uniform in all directions. Furthermore, when a predetermined voltage is applied, the liquid crystal molecules are substantially horizontal to change to a white state.

However, in the MVA liquid crystal panel, there is a problem that a response speed when a black state at a drive voltage of about 1V is switched to a low brightness halftone state at a drive voltage of about 2 to 3V is slower than the TN mode liquid crystal panel.

It is considered that this is because, since the rubbing process in the vertical alignment film is not carried out in the MVA type liquid crystal and the alignment directions of the liquid crystals in a fine region direct to various directions in a state that non-voltage is applied, when a drive voltage is low at about 2 to 3V, it takes some time to align the alignment directions of all the liquid crystals to predetermined directions.

Furthermore, when the black state at the drive voltage of about 1V is switched to a high brightness halftone state at the drive voltage of about 3 to 4V, or when the black state at the drive voltage of about 1V is switched to a white state at the drive voltage of about 5V, as the brightness is overshot, there is a problem that a display impression is worse.

It is considered that this is because, as a moment of rotating the alignment direction of the liquid crystal increases at the drive voltage of about 3V or more, the alignment direction of the liquid crystal rotates over the target alignment direction.

Furthermore, when the black state is switched to a halftone state or so, the halftone state or so is affected by not only the black state shortly before that but also a further previous display state, and the brightness may be overshot. It is considered that this is because the alignment state of the liquid crystal in the black state shortly before that differs due to the previous alignment state of the liquid crystal.

Then, it is an object of the present invention to provide a liquid crystal display device having a drive circuit in which when driving the MVA type liquid crystal panel in which n type liquid crystals are aligned vertically, a response time when the black state is switched to the low brightness halftone state is lessened, and the overshoot when the black state is switched to the halftone state or the white state is diminished; and its drive method.

DISCLOSURE OF THE INVENTION

The above object is attained by providing the following liquid crystal display device: The liquid crystal display device includes domain restriction structure for restricting so that a liquid crystal is provided between a pixel electrode and a counter electrode to which voltage is applied, and an alignment of the liquid crystal is substantially vertical when non-voltage is applied, substantially horizontal when a predetermined voltage is applied, and inclined when a smaller voltage than the predetermined voltage is applied, and further a direction that the alignment of the liquid crystal is inclined is set to be a plurality of parts in each pixel when a voltage smaller than the predetermined voltage is applied, and further comprises.

A drive circuit in which when the pixel is changed from a first transmittance to a second transmittance greater than the first transmittance, a voltage greater than a first target drive voltage corresponding to the second transmittance is

applied on a pixel electrode in a first period of changing to the second transmittance, and the first target display voltage is applied in a second period after the first period.

According to the present invention, when the liquid crystal in the pixel is changed from the first transmittance to the second transmittance, as a voltage greater than the first target drive voltage is applied in the first period, and the first target display voltage is applied in the second period after the first period, in the MVA type liquid crystal panel in which the alignment directions of the liquid crystal in a minute region direct to various directions in a state that a voltage is applied, the response time when the alignment direction of the liquid crystal therein is changed can be reduced. Accordingly, it is possible to provide the liquid crystal display device with a wide viewing angle and a superior response characteristic.

Furthermore, in the drive circuit of the liquid crystal display device according to the present invention, when the pixel is changed from the first transmittance to a third transmittance greater than the second transmittance, a second target drive voltage in correspondence with the third transmittance is applied on the pixel electrode in the first period of changing to the third transmittance.

According to the present invention, when the liquid crystal in the pixel is changed from the first transmittance to the third transmittance much greater than that, as the second target drive voltage in correspondence with the third transmittance is applied in the first period, it is possible to reduce the response time without causing the overshoot with respect to the change in the alignment of the liquid crystal. Accordingly, it is possible to provide the liquid crystal display device which is free of flicker due-to the overshoot, and has the superior response characteristic.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an equivalent circuit of a MVA type liquid crystal panel according to an embodiment of the present invention;

FIGS. **2**A and **2**B are schematic views of the MVA type liquid crystal panel according to the embodiment of the present invention;

FIGS. **3**A, **3**B and **3**C are waveform diagrams of a drive voltage of a liquid crystal display device according to the embodiment of the present invention;

FIGS. **4**A and **4**B are response characteristic diagrams (I) of transmittance of the MVA type liquid crystal panel according to the embodiment of the present invention;

FIGS. **5**A and **5**B are response characteristic diagrams (II) of transmittance of the MVA type liquid crystal display panel according to the embodiment of the present invention;

FIGS. **6**A and **6**B are diagrams for explaining the response characteristic of transmittance;

FIG. **7** is a response characteristic diagram (III) of transmittance of the MVA type liquid crystal panel according to the embodiment of the present invention;

FIG. **8** is a relational diagram between a drive voltage and a compensation voltage according to the embodiment of the present invention;

FIG. **9** is a schematic view of the entire of the liquid crystal display device according to the embodiment of the present invention;

FIG. **10** is a cross-sectional view when a drive voltage is not applied on the MVA type liquid crystal panel according to the embodiment of the present invention;

FIG. **11** is an explanatory view when the drive voltage is applied on the MVA type liquid crystal panel according to the embodiment of the present invention;

FIG. **12** is a diagram showing a relationship between the drive voltage and the panel transmittance;

FIG. **13** is a diagram showing a relationship between the drive voltage Voff and a response time to a halftone;

FIG. **14** is a cross-sectional view of the MVA type liquid crystal panel according to the embodiment of the present invention;

FIG. **15** is a top view of the MVA type liquid crystal panel of FIG. **14**;

FIG. **16** is a diagram showing a relationship between the drive voltage and the panel transmittance after lamination of a retardation film;

FIG. **17** is a cross-sectional view of the MVA type liquid crystal panel according to the embodiment of the present invention;

FIG. **18** is a top view of the MVA type liquid crystal panel of FIG. **17**;

FIG. **19** is a structural view of the liquid crystal display device according to the embodiment of the present invention;

FIGS. **20**A, **20**B and **20**C are explanatory views showing a compensation principle according to the embodiment of the present invention;

FIG. **21** is a waveform diagram when an overshoot generates in a first frame under influences of a −2 frame;

FIG. **22** is a diagram showing a relationship between a drive voltage Vn−2 of the −2 frame and maximum transmittance Tp**1** of the first frame;

FIG. **23** is a diagram showing a relationship between a drive voltage Vn−3 of a −3 frame and the maximum transmittance Tp**1** of the first frame;

FIG. **24** is a waveform diagram when the overshoot generates when temperatures rise;

FIG. **25** is a diagram showing a relationship between the maximum transmittance Tp**1** of the first frame and a drive voltage Vn−1 shortly before that; and

FIG. **26** is a diagram showing a relationship between the maximum transmittance Tp**1** of the first frame and the drive voltage Vn−1 shortly before that at 45° C.

BEST MODE FOR CARRYING OUT THE INVENTION

Hereinafter, an embodiment of the present invention will be described with reference to the drawings. However, such the embodiment does not restrict a technical scope of the present invention.

[First Embodiment]

FIG. **1** is an equivalent circuit of a MVA type liquid crystal panel **1** according to an embodiment of the present invention. The actual MVA type liquid crystal panel **1** has 1024×3×768 pixels, for example, when a color display is made, but here shows the case of 3×3 pixels.

The MVA type liquid crystal panel **1** is assorted into respective pixels by longitudinal source electrode lines S**0**, S**1**, S**2** and transverse gate electrode lines G**0**, G**1**, G**2**, and has TFTs **2** to **10** in each of respective pixels. A source electrode S and a gate electrode G of the TFTs **2** to **10** are connected to the source electrode lines S**0** to S**2** and the gate electrode lines G**0** to G**2**, respectively, and a drain electrode D is connected to pixel electrodes **12** to **20**.

The pixel electrodes **12** to **20** are transparent electrodes of ITO (Indium Tin Oxide), etc., and a drive voltage is applied on liquid crystal pixels **22** to **30** inserted between the pixel electrode and a counter common electrode **32**. The common

electrode **32** is an ITO transparent electrode covering the substantially entire plane of a liquid crystal panel, and a common voltage Vcom is applied thereon.

FIG. **2** is a schematic view of the MVA type liquid crystal panel **1** according to this embodiment, and FIG. **2**A is a plane view seen from upward of partial pixel electrodes **15** to **17** in FIG. **1**, and FIG. **2**B is a cross-sectional view taken along line A—A of FIG. **2**A.

As shown in FIG. **2**A, a projection **40** bending zigzag is provided on the pixel electrodes **15** to **17** . This projection **40** functions as domain restriction structure which splits its alignment direction of a liquid crystal in one pixel into a plurality of parts. The pixel electrode **16** exists in a part assorted by a source electrode line S**1** and a gate electrode line G**1**, and is connected to a TFT **6**. Incidentally, a CS electrode **41** is an electrode for forming auxiliary capacitance.

Furthermore, as shown in FIG. **2**B, the projections **40** are formed alternately in both the common electrode **32** and pixel electrodes **15** to **17**, and a vertical alignment film (not shown) is provided thereon. Liquid crystal molecules **42** are aligned substantially vertically to a surface of an electrode by a vertical alignment film when non-voltage is applied, but as the vertical alignment film is not rubbed, the liquid crystal molecules **42** existing on a lateral inclined plane of the projection **40** are apt to align vertically to the inclined plane. Therefore, the liquid crystal molecules **42** of the part are inclined at only a predetermined angle.

The liquid crystal molecules **42** inclined in a part of the projection **40** perform such a trigger role as determining alignment directions of the other liquid crystal molecules **42** when voltage is applied. For this reason, when voltage is applied, as the directions that the liquid crystal molecules **42** are inclined are split into a plurality of parts in one pixel, visual angle dependency disappears, thereby obtaining omnidirectional uniform display.

FIG. **3** is a waveform diagram of a drive voltage of the liquid crystal display device according to the embodiment of the present invention. FIG. **3**A is a waveform of a gate voltage Vg to be applied on a gate electrode of TFT, and FIGS. **3**B and **3**C are examples of waveforms of a source voltage Vs to be applied on a source electrode of the TFT. When the TFT is energized by applying the gate voltage Vg, this source voltage Vs becomes a drive voltage to be applied on respective liquid crystal pixels **22** to **30**.

For example, in FIG. **1**, if the source voltage Vs is applied on the source electrode line S**1**, and the gate voltage Vg is applied on the gate electrode line G**1**, TFT **6** is conductive and the drive voltage is applied on the pixel electrode **16** corresponding to the liquid crystal pixel **26**.

Furthermore, the source voltage Vs of FIGS. **3**B and **3**C, is inverted every frame period with reference to a potential Vcom of the common electrode **32**. This is because, since if a unidirectional voltage is always applied on the liquid crystal, the liquid crystal is deteriorated, the liquid crystal is driven at AC voltage.

FIG. **3**B shows the case where a non-inverted drive voltage Vp is applied on the liquid crystal pixel in a first frame period Tf**1** starting from time 0 and in a third frame period Tf**3** starting from time 2T, and the inverted drive voltage Vp is applied thereon in a second frame period Tf**2** starting from time T and in a fourth frame period Tf**4** starting from time 3T. Generically, an alignment change of the liquid crystal due to the drive voltage application is slow, and for changing the liquid crystal alignment to transmittance in correspondence with the drive voltage Vp, it is necessary that the drive voltage Vp is continuously applied over several frame periods. In the drive voltage waveforms of FIG. **3**B, Vp is continuously applied over first to fourth frame periods in the same manner as such conventional drive voltage waveforms.

FIG. **3**C shows an improved drive voltage waveform according to the embodiment of the present invention, and for improving a response speed and an overshoot of the liquid crystal pixel, a drive voltage Vp**1** of the first frame period Tf**1** is greater than a drive voltage Vp**2** of a second frame period Tf**2** and on.

According to the embodiment of the present invention, in correspondence with a type of transmittance change of the liquid crystal in the pixel, the drive voltage waveform of FIG. **3**C and the drive voltage waveform of FIG. **3**B are distinguished occasionally. Namely, a drive voltage ratio Vp**1**/Vp**2** which optimizes the response speed and overshoot is different according to a target transmittance of the liquid crystal pixel. Then, a response characteristic of the transmittance will be explained below.

FIGS. **4** to **7** are diagrams for explaining the response characteristic of transmittance of the MVA type liquid crystal panel **1** according to the embodiment of the present invention. FIG. **4**A shows the response characteristic, in a case where the target drive voltage Vp**2** is set as 2.5V in order to change transmittance of a certain liquid crystal pixel from 0% to about 2%, when the drive voltage Vp**1** of the first frame period Tf**1** is set to be 0.8 times the drive voltage Vp**2** of the second frame period Tf**2** and on (Vp**1**/Vp**2**=0.8), and when the drive voltage Vp**1** is equal to the drive voltage Vp**2** (Vp**1**/Vp**2**=1), and when the drive voltage Vp**1** is set to be 1.25 times the drive voltage Vp**2** (Vp**1**/Vp**2**=1.25).

Furthermore, FIG. **4**B shows the response characteristic in a case where the target drive voltage Vp**2** is set as 3V in order to change transmittance from 0% to about 8%, when the drive voltage Vp**1** is equal to the drive voltage Vp**2** (Vp**1**/Vp**2**=1), and when the drive voltage Vp**1** is set to be 1.1 times the drive voltage Vp**2** (Vp**1**/Vp**2**=1.1), and when the drive voltage Vp**1** is set to be 1.25 times the drive voltage Vp**2** (Vp**1**/Vp**2**=1.25), and when the drive voltage Vp**1** is set to be 1.4 times the drive voltage Vp**2** (Vp**1**/Vp**2**=1.4), and when the drive voltage Vp**1** is set to be 2 times the drive voltage Vp**2** (Vp**1**/Vp**2**=2).

From the response characteristic of FIG. **4**, when a black state having transmittance of almost 0% is switched to a low brightness halftone state having transmittance of about 10%, if the drive voltage ratio Vp**1**/Vp**2** is set as 1.25, it is understood that the response time is lessened without the overshoot. Namely, the alignment change of the liquid crystal is completed in about a 1-frame period (T=16.7 ms) from switching of the display, thereby changing to the target transmittance.

On the other hand, when Vp**1**/Vp**2** is set to be 0.8, 1 and 1.1, the response speed is slow and it takes a 2-frame period or more until the liquid crystal reaches the target transmittance. If so, when an animation, etc. is displayed, an image is hard to see as the image falls into disorder. Furthermore, when Vp**1**/Vp**2** is set to be 1.4 and 2, the response speed is fast, but an overshoot of the transmittance is generated and this contributes to a flicker of a display screen.

As described above, the vertical alignment film of the MVA type liquid crystal panel **1** is not rubbed, therefore the alignment directions of the liquid crystal in a minute region direct to various directions in a state that non-voltage is applied. For this reason, when the transmittance is changed from 0 to a second transmittance, it is considered that as the target drive voltage Vp**2** in correspondence with the second transmittance is a low voltage of about 2 to 3V, it takes a lot

of time to rotate the alignment directions of all the liquid crystals to a predetermined direction. Accordingly, it is considered that if the drive voltage Vp**1** of the first frame period is set to be 1.25 times the target drive voltage Vp**2**, an optimal rotation moment can be given to liquid crystal molecules, and the response speed of the liquid crystal can be reduced.

In this method, when a black state having transmittance of almost 0% is switched to a low brightness halftone state having transmittance of about 10% or less, a drive waveform of FIG. **3**C is preferable. With this drive waveform, as shown in FIG. **4**, the target transmittance can be reached in a 1-frame period. Accordingly, the response completion is possible in each frame and an animation display is smoothed.

FIG. **5**A shows the case where the target drive voltage Vp**2** is set to be 3.5V so that transmittance is changed from 0% to about 12%, and the drive voltage Vp**1** of the first frame period is set to be 0.8, 1 and 1.25 times the target drive voltage Vp**2**.

In this method, when the black state is switched to a high brightness halftone state that transmittance is about 10 to 15%, if the drive voltage ratio Vp**1**/Vp**2**=1, it is comprehensive that the response time is decreased without the overshoot. In this case, when Vp**1**/Vp**2**=0.8, the response speed is slow, inversely when Vp**1**/Vp**2**2=1.25, the response speed is fast, but the overshoot is generated to contribute to a flicker of a display screen.

It is considered that this is because when the target drive voltage Vp**2** is about 3V or more, as a moment of rotating the alignment direction of the liquid crystal increases, if Vp**1**/Vp**2** is increased, this contributes to the overshoot, inversely as the target drive voltage Vp**2** is high, the response speed is sufficiently short even at the drive voltage ratio Vp**1**/Vp**2**=1.

FIG. **5**B shows the case where the target drive voltage Vp**2** is set to be 5.5V in order to change transmittance from 0% to about 16%, and the drive voltage Vp**1** of the first frame period is set to be 0.8, 1 and 1.25 times the target drive voltage Vp**2**.

In this method, when the black state is switched to a white state having transmittance of about 15% or over, if the drive voltage ratio Vp**1**/Vp**2**=1.25, it is comprehensive that the response time is lessened without the overshoot. In this case, when Vp**1**/Vp**2**=0.8 or 1, the response speed is fast, but the overshoot is generated, contributing to a flicker of the display screen.

It is considered that this is because, when the drive voltage Vp**1** is about 5V or more, liquid crystal elements in a projection part of the domain restriction structure start aligning. Namely, as shown in FIG. **6**A, the drive voltage Vp**1** is divided into a voltage Vpt and a voltage Vpn in a region of the projection **40**, and the voltage Vpt smaller than the drive voltage Vp**1** is applied to a liquid crystal molecule **45** on the region of the projection **40**. In this case, when the drive voltage Vp**1** is about 5V or less, as the voltage Vpt to the liquid crystal molecule on the region of the projection **40** is a threshold or less of the alignment of the liquid crystal molecule **45**, the liquid crystal molecules **45** do not move. Accordingly, it is considered that when Vp**1**/Vp**2**=0.8 or 1, the operation of the liquid crystal molecules excluding the region of the projection **40** is dominant, therefore the response speed increases, the overshoot is generated.

On the other hand, when the drive voltage Vp**1** is about 5V or more, as shown in FIG. **6**B, as the voltage Vpt of the region of the projection **40** is the threshold or more of the alignment of the liquid crystal molecule **45**, the liquid crystal molecule **45** starts moving. However, as the alignment direction of the liquid crystal molecule **45** is not immediately stabilized, the entire response speed decreases. Accordingly, it is considered that when Vp**1**/Vp**2**=1.25, the operation of the liquid crystal molecule **45** on the region of the projection **40** starts in the first frame period Tf**1**, and as the operation delays, the overshoot lowers.

In this method, when the black state is switched to the white state having transmittance of about 15% or more, if the drive voltage ratio Vp**1**/Vp**2**=1.25, in comparison with Vp**1**/Vp**2**=1 and 0.8, the response speed can be optimized without the overshoot.

As is apparent from the results of FIGS. **4** and **5**, (1) when the display of a certain pixel is switched from the black state to the low brightness halftone state, it is preferable that the drive voltage VP**1** of the first frame period Tf**1** is set to be, for example, 1.25 times the drive voltage VP**2** of the second frame period Tf**2** and on; (2) when the black state is switched to the high brightness halftone state, it is preferable that the drive voltage VP**1** is equal to the drive voltage VP**2**; and (3) when the black state is switched to the white state, it is preferable that the drive voltage VP**1** is set to be, for example, 1.25 times the drive voltage VP**2**. Accordingly, in the cases of (1) and (3) above, a waveform of FIG. **3**C is preferable, and in the case of (2) above, the waveform of FIG. **3**B is preferable. Incidentally, the above 1.25 times are downright one example, and in case of (1) and (3) above, in principle, it is necessary to set as Vp**1**>Vp**2**.

FIG. **7** is a diagram showing the response characteristic of a preferable drive voltage and its transmittance according to the embodiment of the present invention when the display of a certain pixel is switched as black low brightness halftone →black→high brightness halftone→black→white→black. The black state at the drive voltage 0.5V is displayed for 4-frame periods from time t**11**, and the low brightness halftone at the target drive voltage Vp**2**=2.5V is displayed for 4-frame periods from time t**12**. This case corresponds to the change from the first transmittance to the second transmittance, and as shown in FIG. **3**C, the drive voltage in the first frame period starting from time t**12** is set to Vp**1**=1.25×Vp**2**=3.1V, and the next second, third and forth frame periods are set as the target drive voltage Vp**2**=2.5V, thereby switching to the low brightness halftone of transmittance about 2% with superior responsiveness.

Next, the black state at the drive voltage 0.5V is displayed for 4-frame periods from time t**13**, and the high brightness halftone at the target drive voltage Vp**2**=3.5V is displayed for 4-frame periods from time t**14**. This case corresponds to the change from the first transmittance to the third transmittance, and as shown in FIG. **3**B, the drive voltage in the first frame period starting from time t**14** and in the next second, third and forth frame periods is set as Vp**1**=Vp**2**=3.5V, thereby switching to the high brightness halftone of transmittance about 12% without an overshoot.

Next, the black state at the drive voltage 0.5V is displayed for 4-frame periods from time t**15**, and the white state at the target drive voltage Vp**2**=5.5V is displayed for 4-frame periods from time t**16**. This case corresponds to the change from the first transmittance to the fourth transmittance, and as shown in FIG. **3**C, the drive voltage in the first frame period starting from time t**16** is set as Vp**1**=1.25×Vp**2**=6.9V, and the next second, third and fourth frame periods are set to the target drive voltage Vp**2**=5.5V, thereby switching to the white state of transmittance about 16% without the overshoot.

In this method, in the liquid crystal display device according to this embodiment, even in either case of switching

from the black state to the low brightness halftone state, from the black state to the high brightness halftone state, and from the black state to the white state, the response time is shortened and also the switching is possible without generating the overshoot.

FIG. **8** is a relational diagram between a drive voltage and a compensation voltage of the liquid crystal pixel according to the embodiment of the present invention. The target drive voltage Vp**2** and transmittance were taken in the axis of abscissas, and the drive voltage Vp**1** and the compensation voltage in the first frame period were taken in the axis of ordinates. Here, the compensation voltage is a difference voltage between the drive voltage Vp**1** and the target drive voltage Vp**2** in the first frame period.

As described above, according to this embodiment, when the first transmittance for the black state is switched to the second transmittance for the low brightness halftone state, the drive voltage Vp**1** of the first frame period is set to be about 1.25 times the target drive voltage Vp**2**. Accordingly, the compensation voltage is set to be about 0.25 times the target drive voltage Vp**2**.

Furthermore, when the first transmittance is switched to the third transmittance for the high brightness halftone state, the drive voltage Vp**1** of the first frame period is substantially equal to the target drive voltage Vp**2**. Accordingly, the compensation voltage is almost 0.

Furthermore, when the first transmittance is switched to the fourth transmittance for the white state, the drive voltage Vp**1** of the first frame period is set to be about 1.25 times the target drive voltage Vp**2**. Accordingly, the compensation voltage is set to be about 0.25 times the target drive voltage Vp**2**.

Incidentally, in FIG. **8**, specific numerical values of the first to third target drive voltages and values of the ratio of Vp**1**/Vp**2** (1.25 times) can be different values according to a characteristic of the liquid crystal, use of the liquid crystal display device, or the like. Furthermore, the compensation voltage correspondingly becomes values depending on the characteristic of the liquid crystal, etc. Furthermore, each boundary of the first, second and third transmittances cannot always be clearly defined. Accordingly, their characteristic diagrams become smooth curves as shown in FIG. **8**.

In the liquid crystal display device according to the embodiment of the present invention, as described later, a relationship between the target drive voltage Vp**2** and the compensation voltage is stored as a table, and as the drive voltage plus the compensation voltage is applied on the liquid crystal pixel, when the display of each liquid crystal pixel is switched, the liquid crystal can be driven by the drive voltage having optimal characteristics of the response speed and the overshoot.

FIG. **9** is a schematic view of the entire of the liquid crystal display device according to the embodiment of the present invention. The liquid crystal display device according to the embodiment comprises a MVA type liquid crystal panel **1**; a drive control part **50** to which a video signal S**10** is supplied; a gate driver part **51** to which a timing signal S**11** is supplied from the drive control part **50**, and which drives gate electrode lines of the MVA type liquid crystal panel **1**; a compensation circuit **52** for generating a compensation voltage signal S**14** of the drive voltage from a target drive signal S**12** in correspondence with the target transmittance of the liquid crystal pixel; a drive voltage adjustment circuit **57** for generating a drive signal S**13** of the liquid crystal pixel from the target dive signal S**12** and the compensation voltage signal S**14**; and a source driver part **59** to which the drive signal S**13** and the timing signal S**11** are supplied, and which drives the source electrode line of the MVA type liquid crystal panel **1**.

Furthermore, the compensation circuit **52** comprises primary and secondary frame memories **53**, **54** for alternately storing the target drive signal S**12** of each of the respective liquid crystal pixels of the MVA type liquid crystal panel **1** in each frame period; and a display status change pixel detection circuit **55** for comparing data of the primary frame memory **53** with data of the secondary frame memory **54**, and detecting pixels of the changed display status, and outputting the compensation voltage signal S**14** to a drive voltage adjustment circuit **57**. In this case, the display status change pixel detection circuit **55** refers to a lookup table **56** storing relational data of the target drive voltage Vp**2** and the compensation voltage when the display status is changed from a status of transmittance 0 shown in FIG. **8**, and generates the compensation voltage signal S**14**.

Namely, the target drive signal S**12** in correspondence with the transmittance of the pixels is output from the drive control part **50** in synchronism with the timing signal S**11**, and alternately stored in the primary and secondary frame memories **53**, **54** in each frame period. In this case, for example, when the first transmittance of a certain pixel is stored in the primary frame memory **53** in the first frame period and the second transmittance of the pixel is stored in the secondary frame memory **54** in the second frame period, the pixel is switched from the first transmittance to the second transmittance. This switching of the pixel display is detected by the display status change pixel detection circuit **55**, which generates the compensation voltage signal S**14** based on data of the lookup table **56**. This compensation voltage signal S**14** is added to the target drive signal S**12** in the drive voltage adjustment circuit **57**, and is supplied to a source driver part **59** as the drive signal S**13**.

In this method, in the liquid crystal display device according to this embodiment, as the liquid crystal pixel is driven based on data of the lookup table **56** acquired from the response characteristic of the liquid crystal pixel, it is possible to optimize the characteristics of the response speed and the overshoot of the liquid crystal pixel. Furthermore, even when the liquid crystal pixel having the different response characteristic is driven, it is possible to realize the optimal response characteristic at all times only by changing the data of the lookup table **56**.

[Second Embodiment]

Next, a liquid crystal display device according to another embodiment of the present invention in which, in displaying a black, a predetermined drive voltage is applied on liquid crystal molecules to be in advance inclined, so that a response time is lessened when the black state is switched to a halftone state, etc., will be explained.

As described above, as the liquid crystal molecules in the vicinity of a projection of a MVA type liquid crystal panel are aligned vertically to an inclined plane of the projection, the liquid crystal molecules have a slight inclined angle even in a state that a drive voltage is not applied. However, the inclination of the liquid crystal molecules in the vicinity of the projections only becomes a trigger which lets the other liquid crystal molecules incline sequentially when the drive voltage is applied, and the liquid crystal molecules away from the projections are aligned substantially vertically to a substrate in a state that the drive voltage is not applied.

In the liquid crystal display device according to this embodiment of the present invention, when a black is displayed in the MVA type liquid crystal panel, a predetermined drive voltage Voff is applied on the liquid crystal molecules to be in advance inclined, and the response time when the black state is switched to the halftone state, etc. is lessened.

FIG. **10** is a cross-sectional view when a drive voltage is not applied on the MVA type liquid crystal panel according to this embodiment. In the MVA type liquid crystal panel according to this embodiment, an electrode **102** of an ITO transparent conductive inter-film, etc., a bank-like structure **103** of a projection, etc., and a vertical alignment film **104** are laminated on a lower face of a substrate **101** of glass, etc., and a common electrode **108**, the bank-like structure **103**, and a vertical alignment film **107** are laminated on an upper face of a substrate **109** of glass, etc., and liquid crystal molecules **105** are sealed up therebetween, and further a polarization plate **106** is provided on the upper face of the substrate **101**, and a polarization plate **110** is provided on the lower face of a substrate **109**.

When the MVA type liquid crystal panel according to this embodiment is, for example, operated in a normally black mode with a transmission structure, a transmission axis of the polarization plate **106** is stationed so as to be perpendicular to the transmission axis of the polarization plate **110**. In the MVA type liquid crystal panel, in a state that the drive voltage is not applied between the electrode **102** and the common electrode **108**, as the liquid crystal molecule **105** is aligned substantially vertically to the substrate **101**, etc., the liquid crystal molecule **105** does not have an optical characteristic of an optical rotation, etc. Accordingly, lights **112** which became a linear polarization by passing the polarization plate **106** cannot pass the polarization plate **110**, so that a black state of transmittance 0 can be obtained.

On the other hand, when the drive voltage is applied between the electrode **102** and the common electrode **108**, the inclination of the liquid crystal molecule **105** starts to have the optical characteristic, and the lights **112** slightly pass the polarization plate **110** to become the halftone state. When the drive voltage between the electrode **102** and the common electrode **108** is further increased, the liquid crystal molecule **105** is horizontalized to the substrate **101**, etc, and a polarization plane of the lights **112** rotates at 90°, and the transmittance of the polarization plate **110** is maximized. This case is a white state.

FIG. **11** is an explanatory view in which in a state that the drive voltage Voff is applied in the MVA type liquid crystal panel according to this embodiment of the present invention, a black is displayed. FIG. **11**A is its cross-sectional view and FIG. **11**B is its plane view. As shown in FIG. **11**A, in the MVA type liquid crystal panel according to this embodiment, even when the black state is carried out, the drive voltage Voff is applied between the electrode **102** and the common electrode **108**, and the liquid crystal molecule **105** is in advance inclined at only an angle θp from a direction vertical to the substrate **101**, etc. Here, the drive voltage Voff is set to be greater than a threshold voltage Vth starting the inclination of the liquid crystal molecule **105**, and also smaller than a value generating transmittance of the liquid crystal panel.

Incidentally, as shown in the plane view of FIG. **11**B, the inclination direction of the liquid crystal molecule **105** is a direction vertical to the bank-like structure **103**. Furthermore, since left and right inclinations of the bank-like structure **103** are different from each other, the liquid crystal molecules **105** are inclined leftward in a region I and a region III of the liquid crystal panel, and rightward in a region II thereof.

In this method, according to this embodiment, the drive voltage Voff displaying a black is set to be higher than the threshold voltage Vth, so that the liquid crystal molecules **105** in the black state are inclined at only the angle θp. Accordingly, when the black state is switched to the halftone state, the liquid crystal molecules **105** can be inclined in a short time up to an angle corresponding to the halftone state, and the response time of the display can be lessened.

FIG. **12** is a diagram showing a relationship between the drive voltage Vp of the liquid crystal molecule **105** and the transmittance Tp of the liquid crystal panel. When the drive voltage Vp is incrementally increased from 0, as describe above, the inclination of the liquid crystal molecule **105** starts at the threshold voltage Vth. However, even if the drive voltage Vp exceeds the threshold voltage Vth, the inclination of the liquid crystal molecule **105** is still small, and the transmittance Tp is substantially 0. The display is still a black.

When the drive voltage Vp exceeds 2V, the transmittance Tp incrementally increases, and the transmittance Tp becomes about 2% at the drive voltage Vp about 2.5V, thereby reaching the low brightness halftone state. Furthermore, when the drive voltage Vp is about 3.5V, the transmittance Tp becomes about 10%, thereby reaching the high brightness halftone state, and when the drive voltage Vp is about 5V, the transmittance Tp becomes about 15% or more, thereby reaching the white state.

In this method, as the MVA type liquid crystal panel according to this embodiment has a region where the transmittance Tp is 0 even at the threshold voltage Vth or more starting the inclination of the liquid crystal molecule **105**, the drive voltage Voff displaying a black can be set to be greater than the threshold voltage Vth, for example, 2V, whereby even in the black state, the liquid crystal molecule **105** can be inclined in advance at only the angle θp. Accordingly, when the black state is switched to the halftone state, etc., the liquid crystal molecule **105** can be inclined in a short time up to an angle corresponding to the halftone state, etc., and the response time of the display can be shortened.

FIG. **13** is a diagram showing a relationship between the drive voltage Voff and a response time τ to a halftone when a state that the drive voltage Voff is applied to display a black is switched to the halftone state at the drive voltage Vp=2.5V. As shown in FIG. **13**, the response time τ in case of the drive voltage Voff=0 is about 95 ms, but if the drive voltage Voff=2V, the response time τ is reduced to about 65 ms.

In this method, the higher the drive voltage Voff displaying a black, the faster the response time when the black state is switched to the halftone state. In this case, as shown in FIG. **12**, since the transmittance Tp of the liquid crystal panel is 0 until the drive voltage Voff reaches about 2V, the drive voltage Voff is set to be about 2V, thereby shortening only the response time without lowering display contrast of the liquid crystal panel.

Incidentally, the MVA type liquid crystal panel according to this embodiment is shown as an example of using the bank-like structure **103** for the purpose of determining the inclination direction of the liquid crystal molecule **105** in FIG. **11**. The present invention is applicable to the whole of VA type liquid crystal panels such as a display panel which uses a slit-like electrode in order to determine the inclination direction of the liquid crystal molecule **105**, a display panel which uses a rubbed vertical alignment film, or the like.

FIG. **14** is a cross-sectional view of the MVA type liquid crystal panel according to the another embodiment of the present invention. In this embodiment, the further greater drive voltage Voff is applied in a black state, and an inclination angle of the liquid crystal molecules is increased, and the response time when the black state is switched to the halftone state is further lessened.

This embodiment differs from the embodiment of FIG. **10** in that an optical characteristic compensating linear phaser

film **120** is provided between the transparent substrate **101** of glass, etc. and the polarization plate **106**. Since the linear phaser film **120** has an optical characteristic reverse to that of the liquid crystal, the linear phaser film **120** can cancel the optical characteristic of the liquid crystal.

Namely, even if the greater drive voltage Voff is applied and the inclination angle θp of the liquid crystal molecule is increased, the linear phaser film **120** can cancel the optical characteristic of the liquid crystal. Therefore, in the MVA type liquid crystal panel laminating the linear phaser film **120**, the inclination angle θp of the liquid crystal molecule in the black state can be increased, and the response time from the black state to the halftone state can be more lessened.

In order to cancel the optical characteristic of the liquid crystal by lamination of the linear phaser film **120**, the linear phaser film **120** in which an optical phase difference Δnd is about 10 nm is stationed so that the delay phase axis **121** is vertical to a delay phase axis (inclination direction) of the liquid crystal molecule **105** as shown in FIG. **15**, namely in parallel to the bank-like structure **103**. This station causes the optical characteristic in the linear phaser film **120** reverse to that of the liquid crystal, and can cancel the optical characteristic of the liquid crystal.

FIG. **16** is a diagram showing a relationship between the drive voltage Vp and the transmittance Tp of the MVA type liquid crystal panel in which the linear phaser film **120** is laminated. The characteristic of the drive voltage about 2V or more of FIG. **16** is equivalent to one in which the characteristic of the transmittance of FIG. **12** not laminating the linear phaser film is shifted in parallel downward by only the transmittance relevant to the optical characteristic of the linear phaser film **120**. Incidentally, in FIG. **16**, the transmittance Tp is not 0 while the drive voltage Vp is 0V to 2V, and this is because the inverse optical characteristic is generated by lamination of the linear phaser film **120**.

In the MVA type liquid crystal panel according to this embodiment, as shown in FIG. **16**, since the drive voltage Vp for setting the transmittance Tp to 0 is 2V or more, the high drive voltage Voff of 2V or more can be applied in the black state. Accordingly, the inclination angle of the liquid crystal molecule can be increased in correspondence with the high drive voltage Voff of 2V or more, and the response time from the black state to the halftone state can be more diminished. Incidentally, when the optical phase difference Δnd of about 10 nm is provided to a visual angle compensating phase difference film usually used in the MVA type liquid crystal panel, the same effect can be realized.

In case where the linear phaser films **120** are laminated, when the alignment directions of the liquid crystal molecules **105** differ according to the region of the display panel, it is necessary that the delay phase axis **121** of the linear phaser film **120** is perpendicular to the delay phase axis (inclination direction) of the liquid crystal molecule **105** in each region. In this case, it is preferable that the linear phaser film **120** is formed inside the display panel, and is brought as near as possible in proximity to the bank-like structure **13** and the liquid crystal layer, and therefore a parallax of each region is lessened.

FIG. **17** is a cross-sectional view of the MVA type liquid crystal panel in which the optical characteristic compensating linear phaser film **120** is formed inside the display panel according to the another embodiment of the present invention. According to this embodiment, as the linear phaser film **120** is formed on the lower face of the substrate **101** of glass, etc., and is near to the bank-like structure **103** and the liquid crystal layer, the parallax of each region can be reduced.

FIG. **18** is a top view of the MVA type liquid crystal panel according to the another embodiment of FIG. **17**. According to this embodiment, as the bank-like structure **103** is formed zigzag, the alignment directions of the liquid crystal molecules **105** also become vertical to the bank-like structure **103** in each of the regions IV, V and VI to be zigzag. Accordingly, the delay phase axis **121** of the linear phaser film **120** is stationed in a direction perpendicular to the delay phase axis (inclination direction) of the liquid crystal molecule **105** in each of the regions IV, V and VI, namely in parallel to the bank-like structure **103**.

In this method, according to this embodiment, as the delay phase axis **121** of the linear phaser film **120** in each of the respective regions is stationed perpendicular to the delay phase axis (inclination direction) of the liquid crystal molecule **105**, the optical characteristic of the liquid crystal can be cancelled by the linear phaser film **120**, and it becomes possible to apply the high drive voltage Voff in the black state. For this reason, the inclination angle θp of the liquid crystal molecule in the black state is increased, and the response time from the black state to the halftone state can be shortened.

[Third Embodiment]

Next, an explanation will be for a liquid crystal display device in which a response time is shortened when a black state is switched to a halftone state, etc., and a liquid crystal display device which reduces an overshoot of a brightness to be generated when the display is switched.

According to the first embodiment above, when the black state is switched to the halftone state, etc., for example, the black state of one frame just before switching to the halftone state is detected, and a drive voltage of a liquid crystal is adjusted by the detection results. However, since a response characteristic from the black state to the halftone state, etc. is affected by not only the black state of the just preceding one frame, but also the display of the frame further before the just preceding frame, a suitable drive cannot be made by detecting only the black state of the just preceding frame, and there may be a case where an overshoot is generated in a brightness.

Then, in the liquid crystal display device according to this embodiment, when the black state is switched to the halftone state, etc., the black states of the just preceding frame and the further prior frame are detected, and a suitable drive voltage is applied, so that the over shoot of the brightness is decreased.

FIG. **19** is a structural view of the liquid crystal display device according to the embodiment of the present invention. The liquid crystal display device according to this embodiment comprises a compensation voltage detection circuit **205** for detecting a drive voltage to be compensated from a video signal; a compensation just preceding voltage detection circuit **202** for detecting the drive voltage one frame before the drive voltage to be compensated; and a just preceding display voltage frame memory **203** for storing the drive voltage detected by the compensation just preceding voltage detection circuit **202**, and the just preceding display voltage frame memory **203** has a bit counter **204** for counting the number of frames when each pixel has the same drive voltage in the continuous frame. Incidentally, a control signal for setting a threshold, etc. of a detection voltage is input from a control circuit **201** to the just preceding display voltage frame memory **203**. The frame memory **203** and the bit counter **204** have regions and counters for the pixels, respectively.

Furthermore, the liquid crystal display device according to this embodiment comprises a compensation voltage generation circuit **206** for generating a compensation voltage to be added to the drive voltage; a compensation judgement circuit **207** for judging whether or not compensation is made from the drive voltage to be compensated and the just preceding drive voltage; a multiplexer **208** for adding the compensation voltage signal to the video signal; a panel drive circuit **209** for driving a liquid crystal display panel **210** according to an output signal of the multiplexer **208**; and the liquid crystal display panel **210**.

In the liquid crystal display device according to this embodiment, for example, when the response characteristic is compensated when switching from the continuous black state to the halftone state, etc., the drive voltage of the black state in the frame just before the compensating halftone state frame is detected by the compensation just preceding voltage detection circuit **202**, and the drive voltage is stored in the just preceding display voltage frame memory **203**.

When it is detected by the bit counter **204** that the black state just before the compensating halftone state frame continues in the predetermined number of frames, and the compensating halftone drive voltage is detected by the compensation voltage detection circuit **205**, the compensation voltage is added to the drive voltage by the multiplexer **208**.

An alignment state of the liquid crystal molecules displaying a black is not necessarily in the initial state at all times, but differs depending on the drive voltage of the preceding frame. However, if the black state continues, for example, in two frames, the alignment state of the liquid crystal molecules becomes substantially an initial state irrespective of the drive voltage of the preceding frame. For this reason, since a state change of the liquid crystal molecules is constant when the black state is switched to the halftone state in this case, the optimal compensation voltage can always be added to the drive voltage for displaying the halftone. Accordingly, the response time is reduced for changing the black state to the halftone state, and also the overshoot of the brightness can be prevented.

FIG. **20** is an explanatory view showing a compensation principle of a drive method according to this embodiment. FIG. **20**A is waveforms of the drive voltage and transmittance in the case of non-compensation. Here, the axis of abscissas is a time, and scales are entered in each of a 1-frame period T. Incidentally, the drive voltage is actually inverted in each of the 1-frame period and applied to liquid crystal molecules, but for conveniences of description of the response characteristic, it is denoted as absolute values.

When the compensation according to this embodiment is not made, as shown in FIG. **20**A, even if a drive voltage Vp**2** displaying a halftone in time 0 is applied, transmittance does not rise immediately, and reaches target transmittance Tp**2** in time 2T and on.

FIG. **20**B is a waveform when the drive voltage Vp**1** greater than Vp**2** is applied in only the first frame period starting from time 0 in order to obtain the optimal drive voltage. In this case, the transmittance rises from time 0, and reaches transmittance Tp**1** of a peak in time T, and thereafter falls to be 0 in time 2T. According to this embodiment, the drive voltage Vp**1** in which the transmittance Tp**1** of a peak of FIG. **20**B is equal to a target transmittance Tp**2** of FIG. **20**A is used as the drive voltage of the first frame. This is shown in FIG. **20**C.

FIG. **20**C is a waveform when the compensation of the response characteristic was made by the drive method according to this embodiment. According to this embodiment, the frames of the black state continue (−3T, −2T, −T), and also when the black state is switched to the halftone state in time 0, the compensation of the drive voltage is made. FIG. **20**C is the case where the black state continues in a 2-frame period of a −2 frame (−2T) and a −1 frame (−T), and also the target drive voltage Vp**2** corresponds to the halftone in time 0, and the drive voltage Vp**1** greater than the target drive voltage Vp**2** is applied in the first frame period (0 to T). According to the drive method of this embodiment, it is possible to reach the target transmittance Tp**1**=Tp**2** in a 1-frame period without generating the overshoot.

Next, when the drive voltage of the first frame (0 to T) is established by the above drive method of the first embodiment, the description will be made that the overshoot is generated in the transmittance Tp**1** of the first frame (0 to T) due to influences of the −2 frame (−2T to −T).

As shown in FIG. **21**, when the −2 frame (−2T to −T) is the halftone state and the drive voltage is Vp**2**, even if the drive voltage of the −1 frame (−T to 0) is 0, as the compensation voltage Vp**1** is applied, the overshoot may generate in the transmittance Tp**1** of the first frame (0 to T). This is because the inclination angle of the liquid crystal molecules inclined in the −2 frame (−2T to −T) is not returned fully to an initial state in the 1-frame (−T to 0). As is understood from FIG. **21**, in addition to the just preceding frame, in correspondence with the drive voltage of the −2 frame period before that, it is preferable to be judged whether or not the compensation voltage is applied.

FIG. **22** is a diagram showing a relationship between a drive voltage Vn−2 of the −2 frame (−2T to −T) and maximum transmittance Tp**1** of the first frame (0 to T) when the drive voltage Vn−1 of the −1 frame (−T to 0) is, for example, 1V. As shown in FIG. **22**, when the drive voltage Vn−2 of the −2 frame (−2T to −T) changes, the maximum transmittance Tp**1** of the first frame (0 to T) changes largely. Accordingly, according to this embodiment, not only the drive voltage Vn−1 of the just prior −1 frame (−T to 0), but also the drive voltage Vn−2 of the further prior −2 frame (−2T to −T) are detected, and the drive voltage Vp**1** of the first frame (0 to T) is determined. Namely, when the black state, etc. continues in the just preceding 2-frame period, the drive voltage Vp**1** of the first frame (0 to T) is established.

FIG. **23** is a diagram showing a relationship between the drive voltage Vn−3 of a −3 frame and the maximum transmittance Tp**1** of the first frame (0 to T) under the same conditions of FIG. **22**. As shown in FIG. **23**, the drive voltage Vn−3 of the −3 frame (−3T to −2T) is smaller in influences exerted on the maximum transmittance Tp**1** of the first frame (0 to T) than the case of the drive voltage Vn−2 of the −2 frame (−2T to −T) shown in FIG. **22**. Accordingly, according to this embodiment, only when the same drive voltage continues in the 2-frame period, the drive voltage of the first frame (0 to T) is set to be Vp**1**, whereby the change of transmittance of the first frame (0 to T) is optimized.

In this method, in the liquid crystal display device according to this embodiment, when the black state continues in the 2-frame periods and also the black state is switched to the halftone state after that, the drive voltage Vp**1** greater than the target drive voltage Vp**2** is applied on the first frame period (0 to T) displaying the halftone. For this reason, in the state change when the liquid crystal molecules are switched from the black state to the halftone state, the change is made from almost an initial state and the overshoot of the brightness can be prevented.

Incidentally, in the MVA type liquid crystal panel, since when the drive voltage is applied, the inclination alignment of the liquid crystal molecules is spread from a bank-like structure, only part of pixels responds in the 1-frame period, and a bound may generate in the second frame (T to 2T) as shown by a dotted line in FIG. **20**C. In the case, the drive voltage Vp**1** is continuously applied in the first and second frames (0 to T, T to 2T), thereby reducing the bound.

Next, the description will be made that when temperature of the liquid crystal panel increases, the overshoot is generated in the transmittance of the liquid crystal panel. FIG. **24** is a waveform diagram of the drive voltage and the transmittance when temperatures of the liquid crystal panel rise. As shown in FIG. **24**, according to the drive method of this embodiment, even when the drive voltage Vp**1** is applied in the first frame period (0 to T), as the response of the liquid crystal is accelerated by an increase in the temperatures, the overshoot may be generated in the transmittance of the first frame (0 to T).

FIG. **25** shows a change of the maximum transmittance Tp**1** of the first frame (0 to T) when temperatures of the

display panel are 25° C., the drive voltage Vp1 of the first frame is 4.0V, 3.5v and 3.0V, and also when the drive voltage Vn−1 of the −1 frame (−T to 0) changes. As shown in FIG. **25**, when the drive voltage Vp**1** of the first frame (0 to T) is 3.0V, if the drive voltage Vn−1 of the −1 frame (−T to 0) changes from 0V to 2V, the maximum transmittance Tp**1** of the first frame (0 to T) changes from about 0% to 2%.

FIG. **26** shows the maximum transmittance Tp**1** of the first frame (0 to T) when temperatures of the display panel are 45° C. under the same conditions as FIG. **25**. As shown in FIG. **26**, when the drive voltage Vp**1** of the first frame (0 to T) is 3.0V, if the drive voltage Vn−1 of the −1 frame (−T to 0) changes from 0V to 2V, the maximum transmittance Tp**1** of the first frame (0 to T) changes from about 3% to 7%. In this method, when the temperatures of the liquid crystal panel increase, the transmittance of the liquid crystal panel increases, and when the compensation voltage Vp**1** is applied as shown in FIG. **24**, the overshoot is generated in the transmittance, and the accurate brightness cannot be displayed.

Then, in the liquid crystal display device according to this embodiment, in the compensation voltage generation circuit **206** shown in FIG. **19**, when the temperatures rise, a temperature compensation is made so as to lower the drive voltage Vp1 of the first frame (0 to T), and this prevents the generation of the overshoot in the transmittance of the display panel. Namely, in FIG. **20**C, when the temperatures of the panel rise, the drive voltage Vp**1** of the first frame (0 to T) is set to be lower as shown by a broken line.

Furthermore, as shown in FIGS. **25** and **26**, when the drive voltage Vn−1 of the −1 frame (−T to 0) changes, the maximum transmittance Tp**1** of the first frame (0 to T) also changes, and as shown in FIG. **12**, if the drive voltage is 2V or less, the transmittance of the display panel is substantially 0. Accordingly, according this embodiment, when the black state is carried out in pixels, the maximum drive voltage is applied on a pixel electrode in the range of displaying a black. Namely, all the drive voltages Vn−1 of 2V or less is summarized to 2V, whereby the calculation of the drive voltage Vp1 of the first frame (0 to T) by the drive voltage Vn−1 of the just preceding display frame (−T to 0) is simplified, thereby decreasing a process load of a drive circuit. Furthermore, when the drive voltage Vn−1 of the −1 frame (−T to 0) is high, as the liquid crystal molecules have been aligned aslant in advance, the bound can be decreased.

The above embodiment explained the MVA type liquid crystal panel having the plurality of regions where the liquid crystals are vertically aligned, but the present invention is not limited to the MVA type liquid crystal panel, but is applicable to even the general VA type liquid crystal panel.

INDUSTRIAL APPLICABILITY

As explained hereinabove, according to the present invention, it is possible to provide the liquid crystal display device in which, when the MVA or VA type liquid crystal panel in which n type liquid crystals are vertically aligned is driven, the response time when the black state is switched to the low brightness halftone state is shortened, and the overshoot when the black state is switched to the high brightness halftone state or the white state is decreased; and its drive method.

What is claimed is:

1. A liquid crystal display device, comprising:

a liquid crystal provided between a pixel electrode and a counter electrode to which a drive voltage is applied;

a domain restriction structure for restricting an alignment of the liquid crystal so that the alignment of the liquid crystal is substantially vertical when non-voltage is applied, substantially parallel when a predetermined voltage is applied, and inclined when a smaller voltage than the predetermined voltage is applied, and further a direction that the alignment of the liquid crystal is inclined is set to be a plurality of parts in each pixel when a voltage smaller than the predetermined voltage is applied; and

a drive circuit in which when the pixel is changed from a first transmittance to a second transmittance greater than the first transmittance, a voltage greater than a first target drive voltage corresponding to the second transmittance is applied between the pixel electrode and the counter electrode in a first period of changing to the second transmittance, and the first target display voltage is applied between the pixel electrode and the counter electrode in a second period after the first period.

2. The liquid crystal display device according to claim **1**, wherein

when the pixel is changed from the first transmittance to a third transmittance greater than the second transmittance, the drive circuit applies a second target drive voltage corresponding to the third transmittance between the pixel electrode and the counter electrode in the first period of changing to the third transmittance.

3. The liquid crystal display device according to claim **2**, wherein

when the pixel is changed from the first transmittance to a fourth transmittance greater than the third transmittance, the drive circuit applies a voltage greater than the third target drive voltage corresponding to the fourth transmittance between the pixel electrode and the counter electrode in the first period of changing to the fourth transmittance, and applies the third target drive voltage between the pixel electrode and the counter electrode in a second period after the first period.

4. A method for driving a liquid crystal display device including a liquid crystal provided between a pixel electrode and a counter electrode to which a voltage is applied, and a domain restriction structure for restricting an alignment of the liquid crystal so that the alignment of the liquid crystal is substantially vertical when non-voltage is applied, substantially parallel when a predetermined voltage is applied, and inclined when a smaller voltage than the predetermined voltage is applied, and further a direction that the alignment of the liquid crystal is inclined is set to be a plurality of parts in each pixel when a voltage smaller than the predetermined voltage is applied, the method comprising:

when the pixel is changed from a first transmittance to a second transmittance greater than the first transmittance, applying a voltage greater than a first target drive voltage corresponding to the second transmittance between the pixel electrode and the counter electrode in a first period of changing to the second transmittance; and applying the first target display voltage between the pixel electrode and the counter electrode in a second period after the first period.

* * * * *

EXHIBIT C

US007304626B2

(12) **United States Patent**
Yanagi et al.

(10) **Patent No.: US 7,304,626 B2**
(45) **Date of Patent: Dec. 4, 2007**

(54) **DISPLAY DEVICE AND DISPLAY METHOD**

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(73) Assignee: **Sharp Kabushiki Kaisha**, Osaka (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 145 days.

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(22) Filed: **Sep. 29, 2005**

(65) **Prior Publication Data**

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Related U.S. Application Data

(60) Division of application No. 10/883,375, filed on Jun. 30, 2004, now Pat. No. 7,027,024, which is a continuation of application No. 10/037,804, filed on Dec. 26, 2001, now Pat. No. 6,867,760, which is a division of application No. 09/275,063, filed on Mar. 23, 1999, now Pat. No. 6,359,607.

(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**
G06G 3/36 (2006.01)

(52) **U.S. Cl.** **345/94**; 345/99

(58) **Field of Classification Search** 345/92, 345/94, 99, 100, 204, 205, 208
See application file for complete search history.

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Primary Examiner—Ricardo Osorio
(74) *Attorney, Agent, or Firm*—Nixon & Vanderhye P.C.

(57) **ABSTRACT**

In the display device and the display method of the present invention, a scanning signal line driving circuit controls falls of a scanning signal line, so as to make level shifts occurring to pixel potentials substantially uniform throughout display plane, the level shifts being caused by parasitic capacitances which parasitically exist in scanning signal lines. Fall waveforms of the scanning signal change at a change rate Sx which is a change quantity per unit time, and by desirably setting the change rate Sx, a change rate Sxl in the vicinity of an input-side end of the scanning signal line and a change rate SxN in the vicinity of the other end thereof are substantially equal to each other, not being influenced by signal delay transmission characteristic which the scanning signal line possesses, like scanning signal line waveforms Vg(**1**, j) and Vg(N, j).

21 Claims, 12 Drawing Sheets

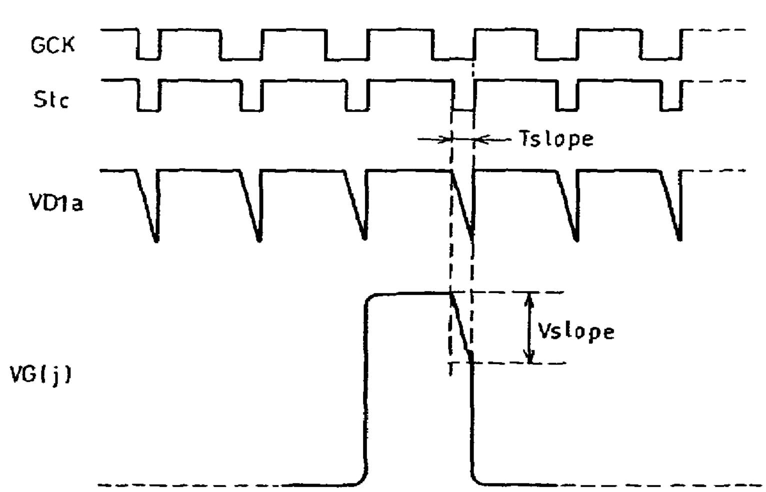

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FIG. 1

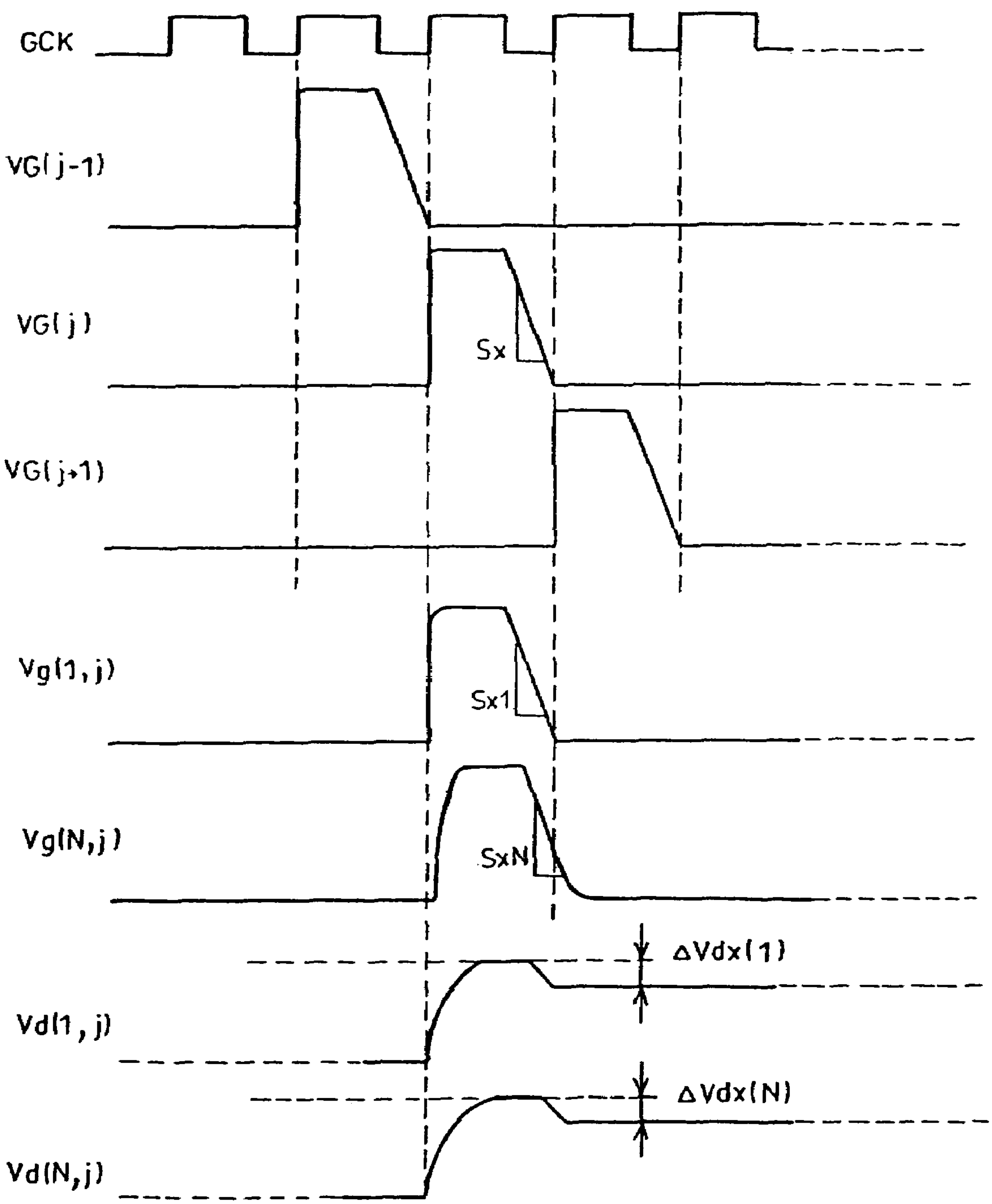


FIG. 2

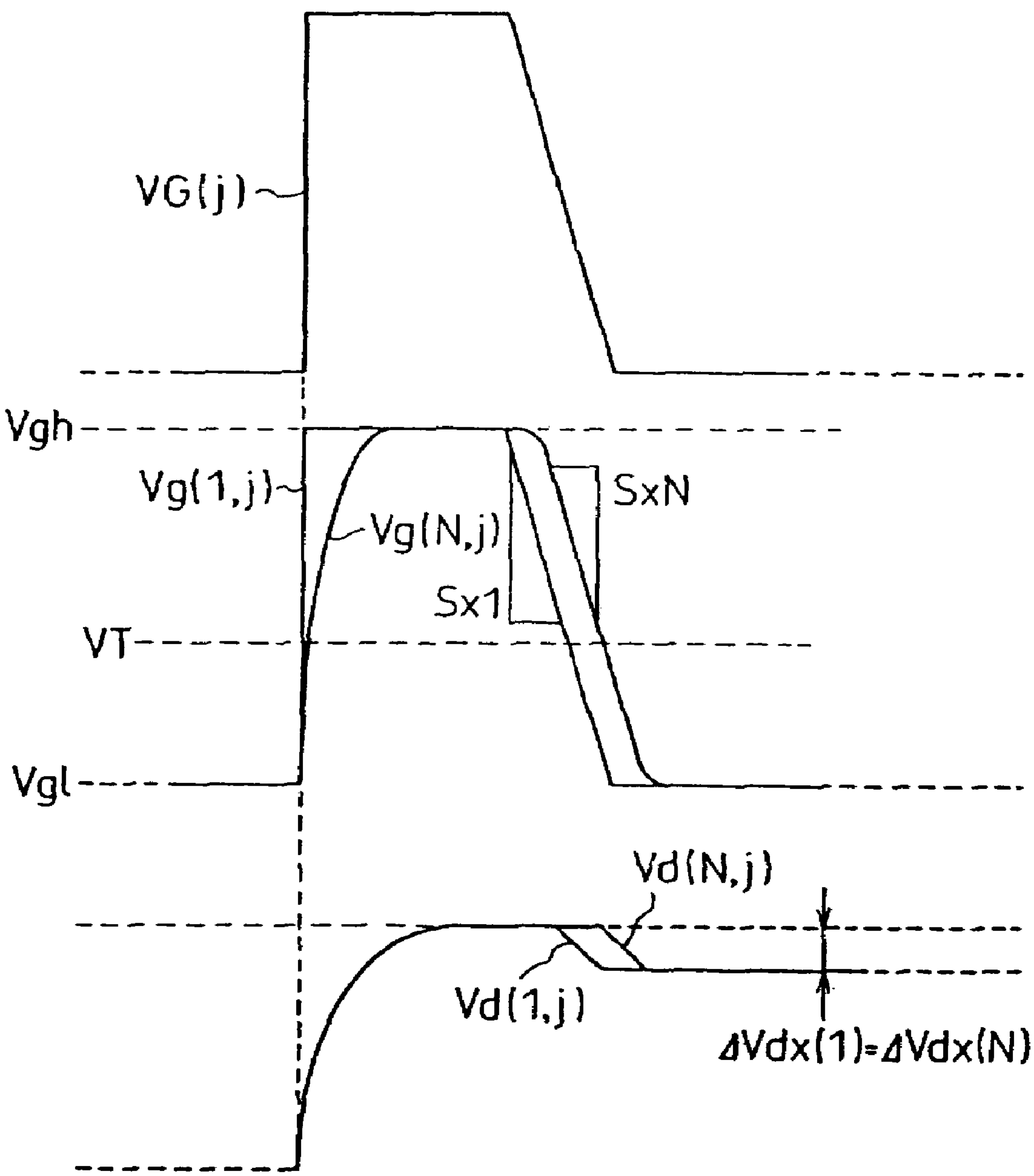


FIG.3

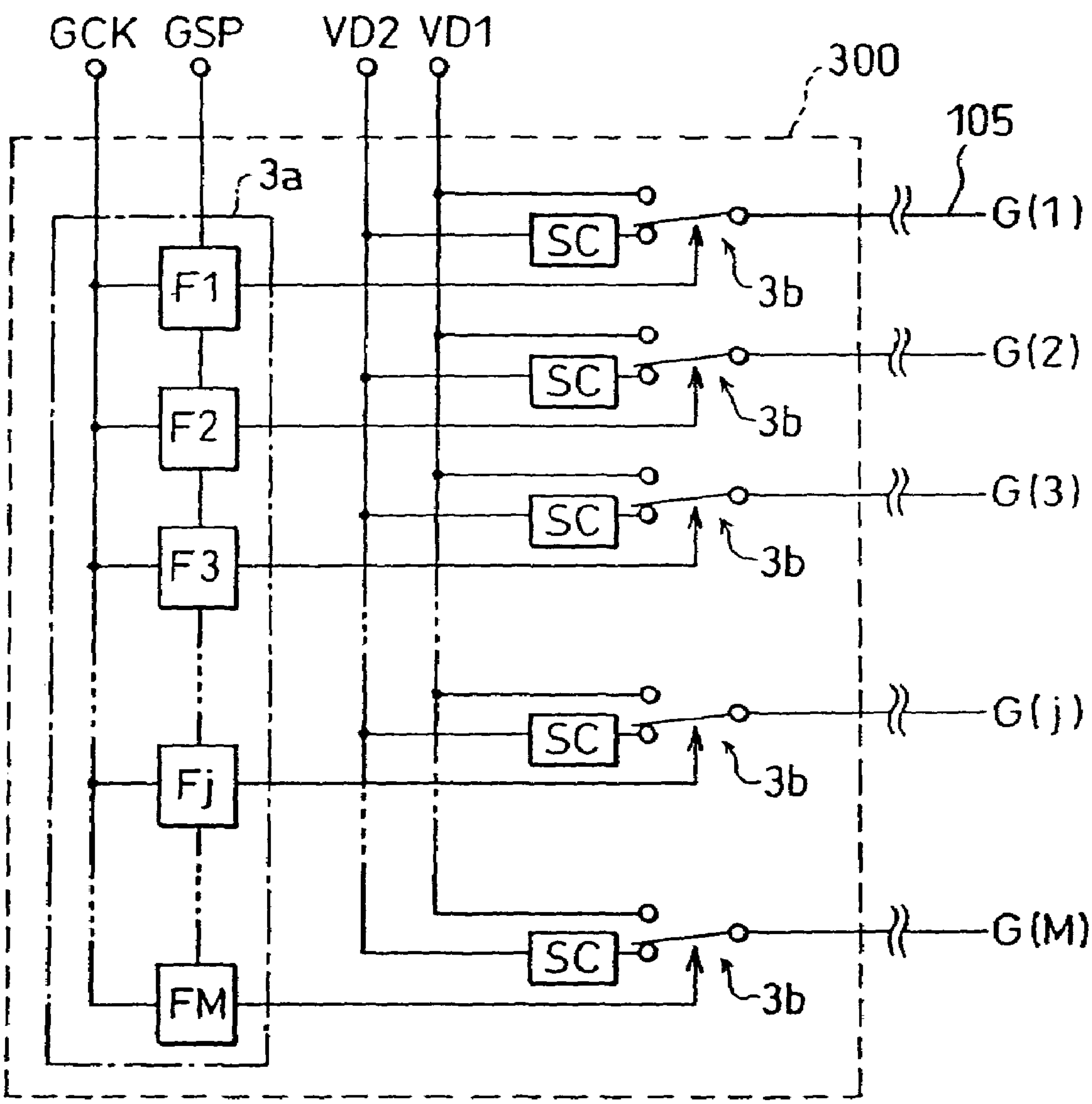

GCK
GSP
VD2
VD1
300
105
3a
F1
F2
F3
Fj
FM
SC
SC
SC
SC
SC
3b
3b
3b
3b
3b
G(1)
G(2)
G(3)
G(j)
G(M)

FIG. 4

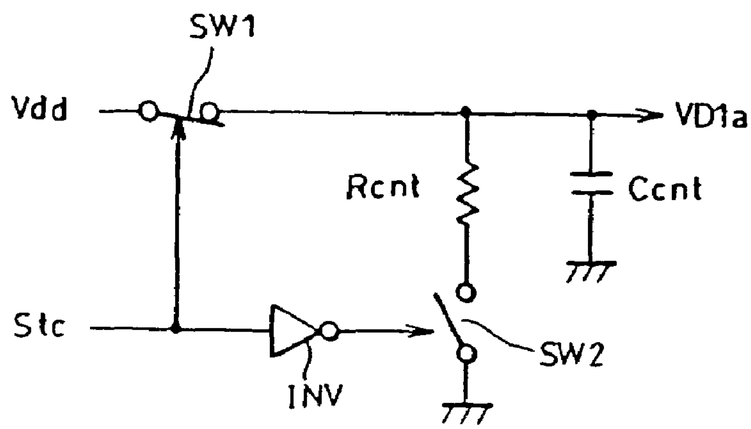

SW1
Vdd
VD1a
Rcnt
Ccnt
Stc
SW2
INV

FIG. 5

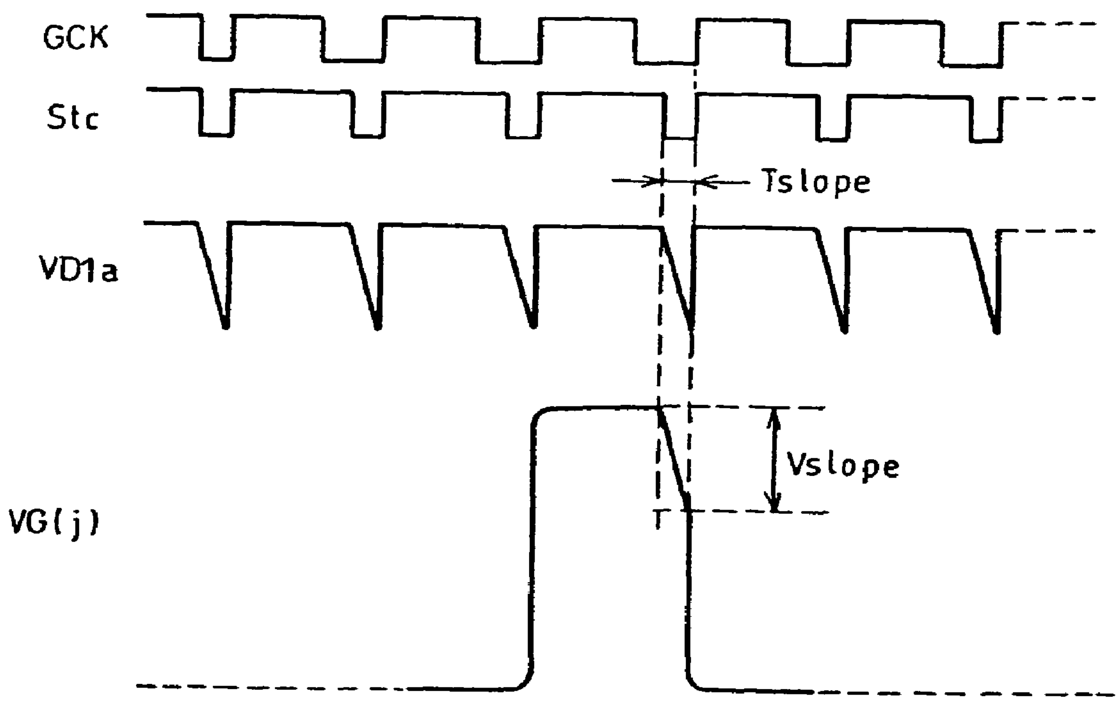

GCK
Stc
Tslope
VD1a
Vslope
VG(j)

FIG.6

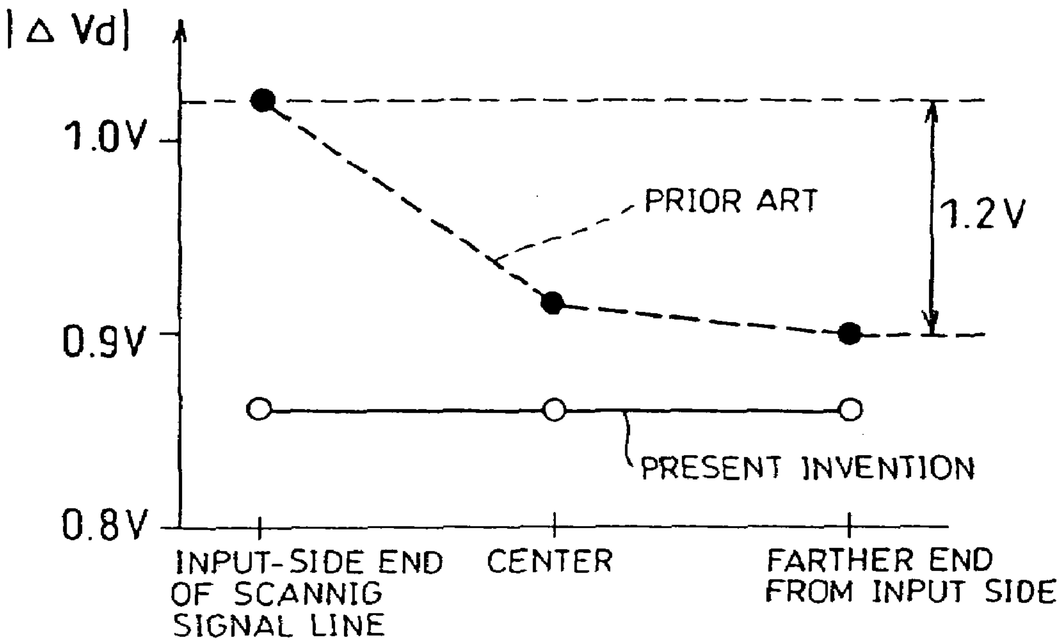

|Δ Vd|
1.0V
0.9V
0.8V
PRIOR ART
1.2V
PRESENT INVENTION
INPUT-SIDE END OF SCANNIG SIGNAL LINE
CENTER
FARTHER END FROM INPUT SIDE

FIG.7

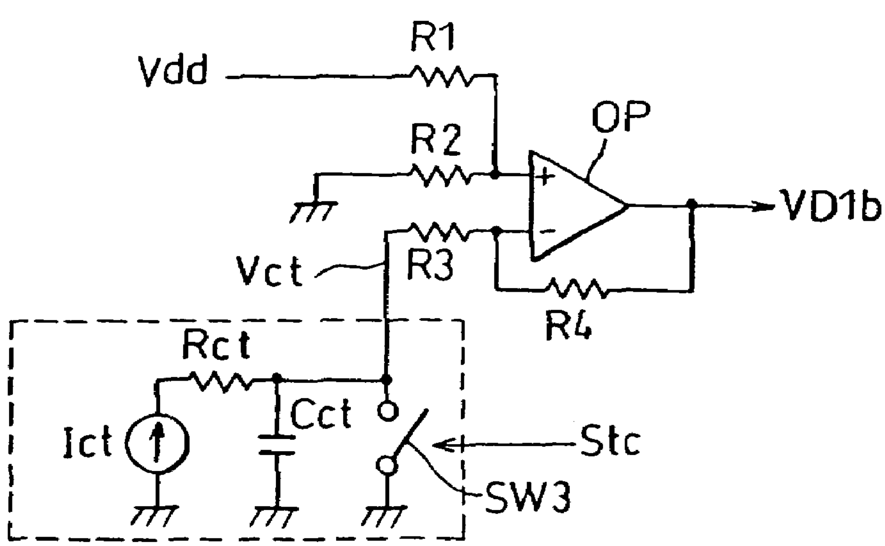

Vdd
R1
R2
OP
VD1b
Vct
R3
R4
Rct
Ict
Cct
Stc
SW3

FIG. 8

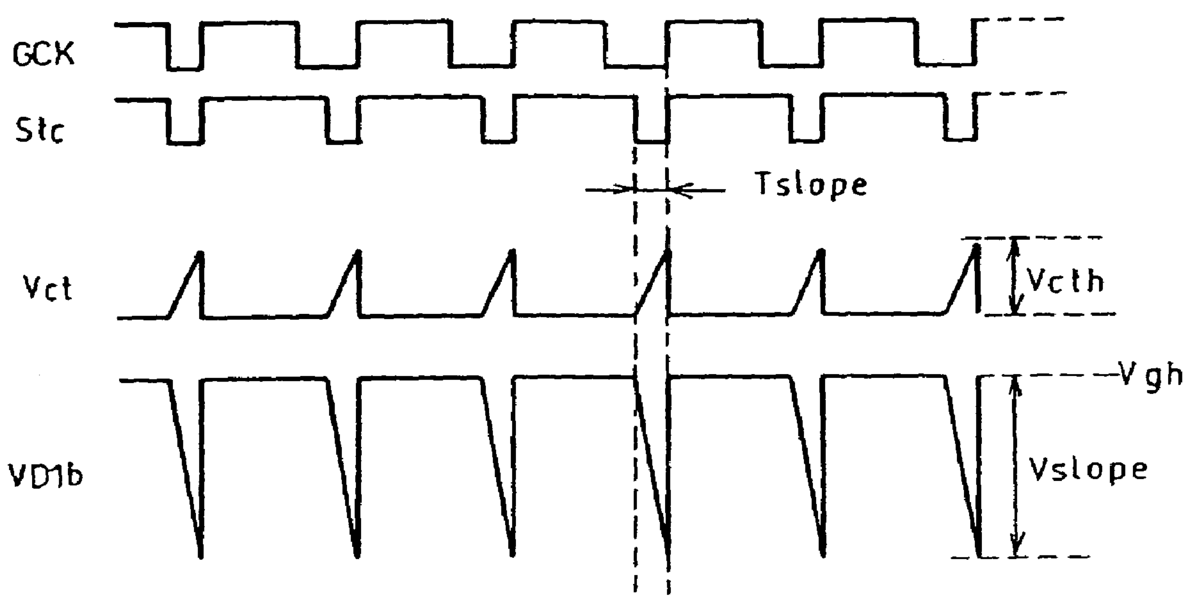


FIG. 9

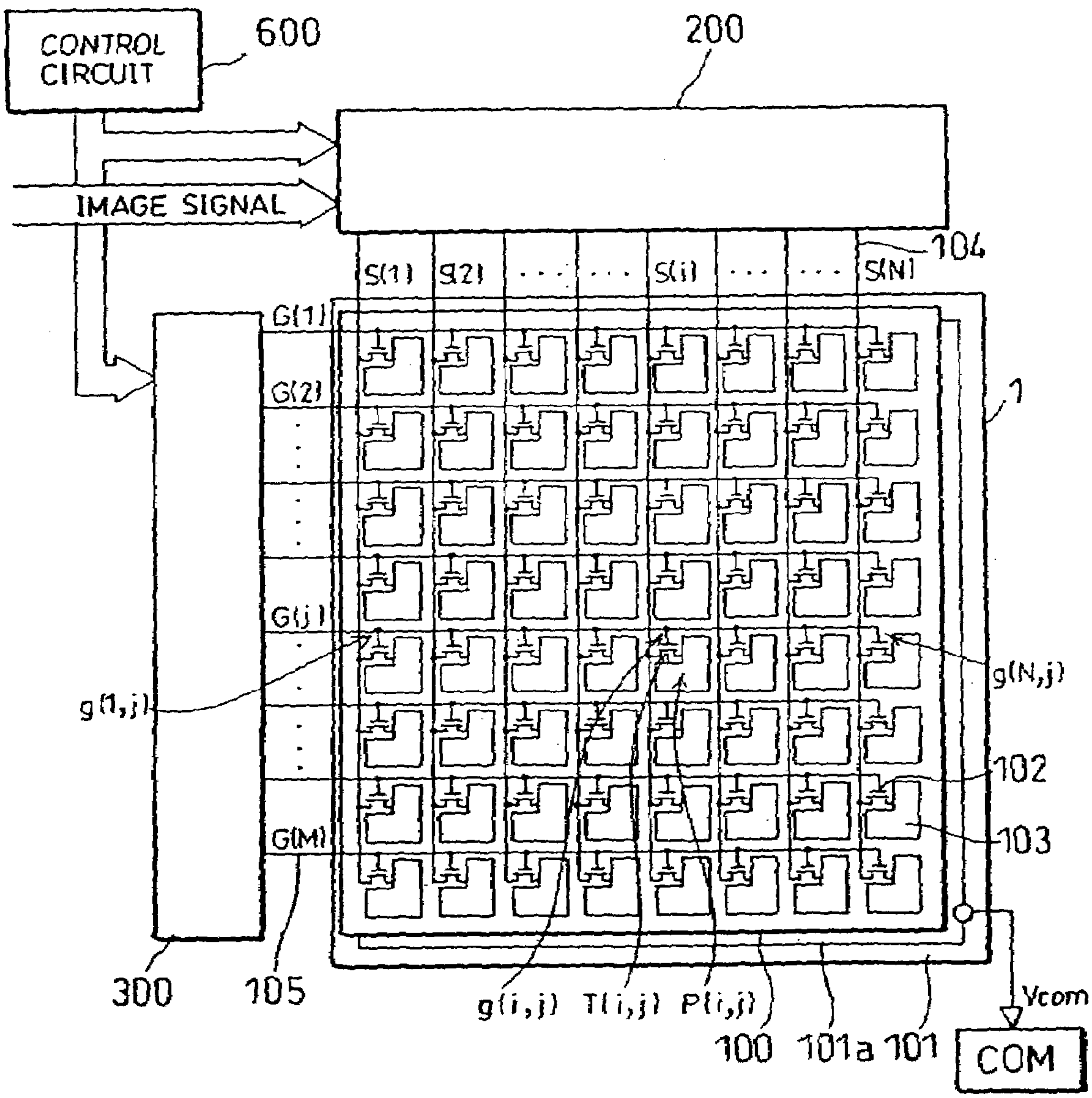

CONTROL CIRCUIT
600
200
IMAGE SIGNAL
104
S(1)
S(2)
S(i)
S(N)
G(1)
G(2)
G(j)
G(M)
1
g(1,j)
g(N,j)
102
103
300
105
g(i,j)
T(i,j)
P(i,j)
100
101a
101
Vcom
COM

FIG.10

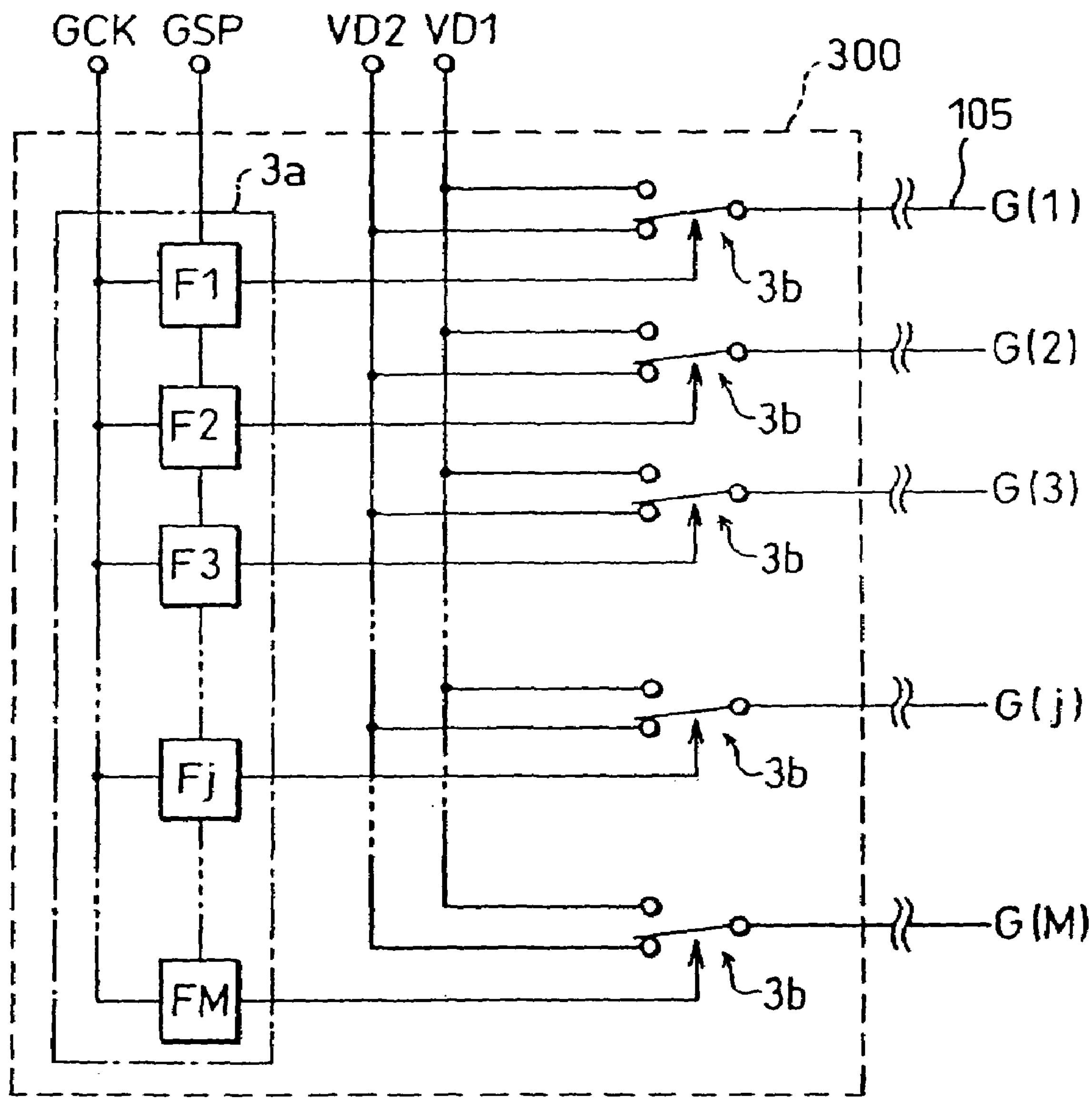


FIG.11

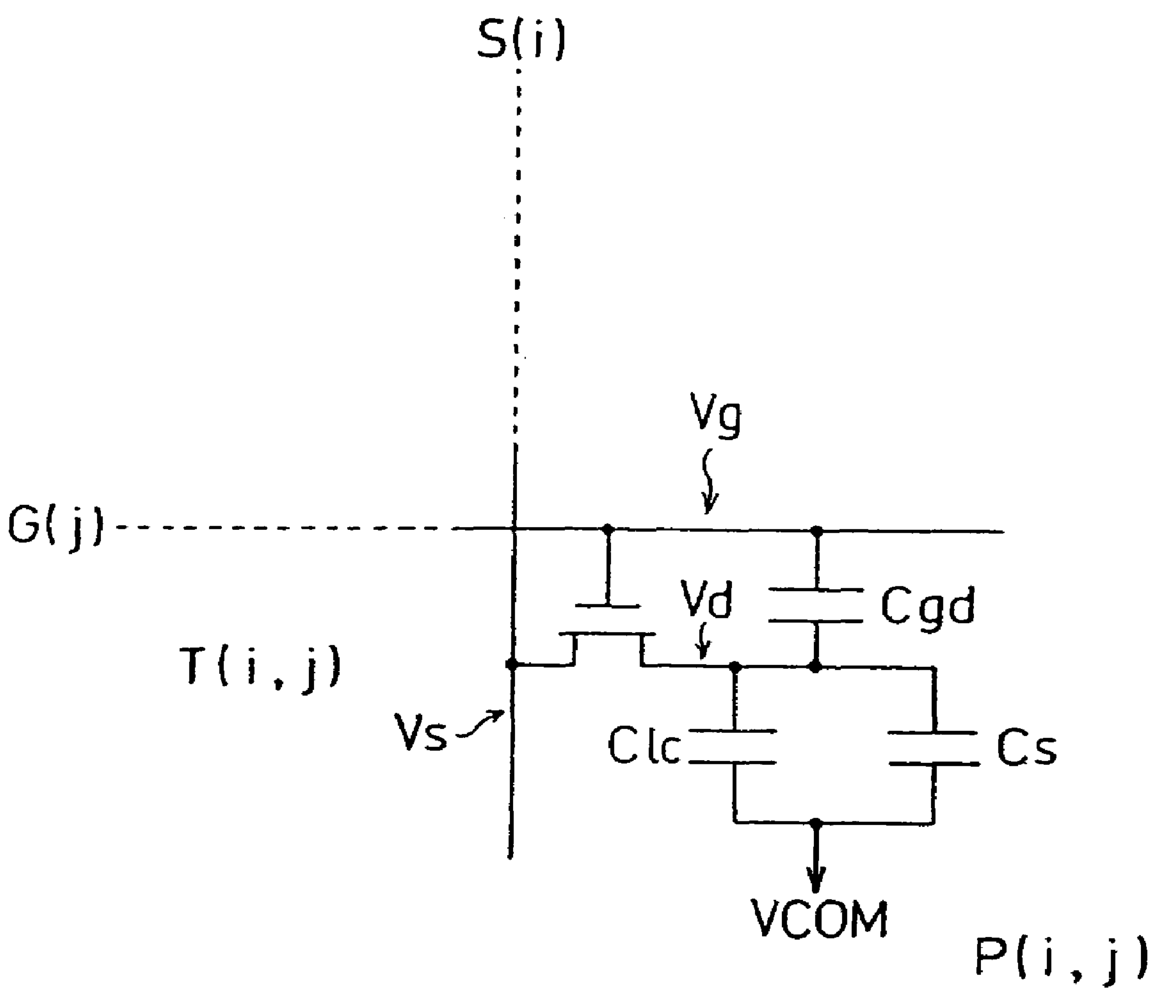


FIG.12

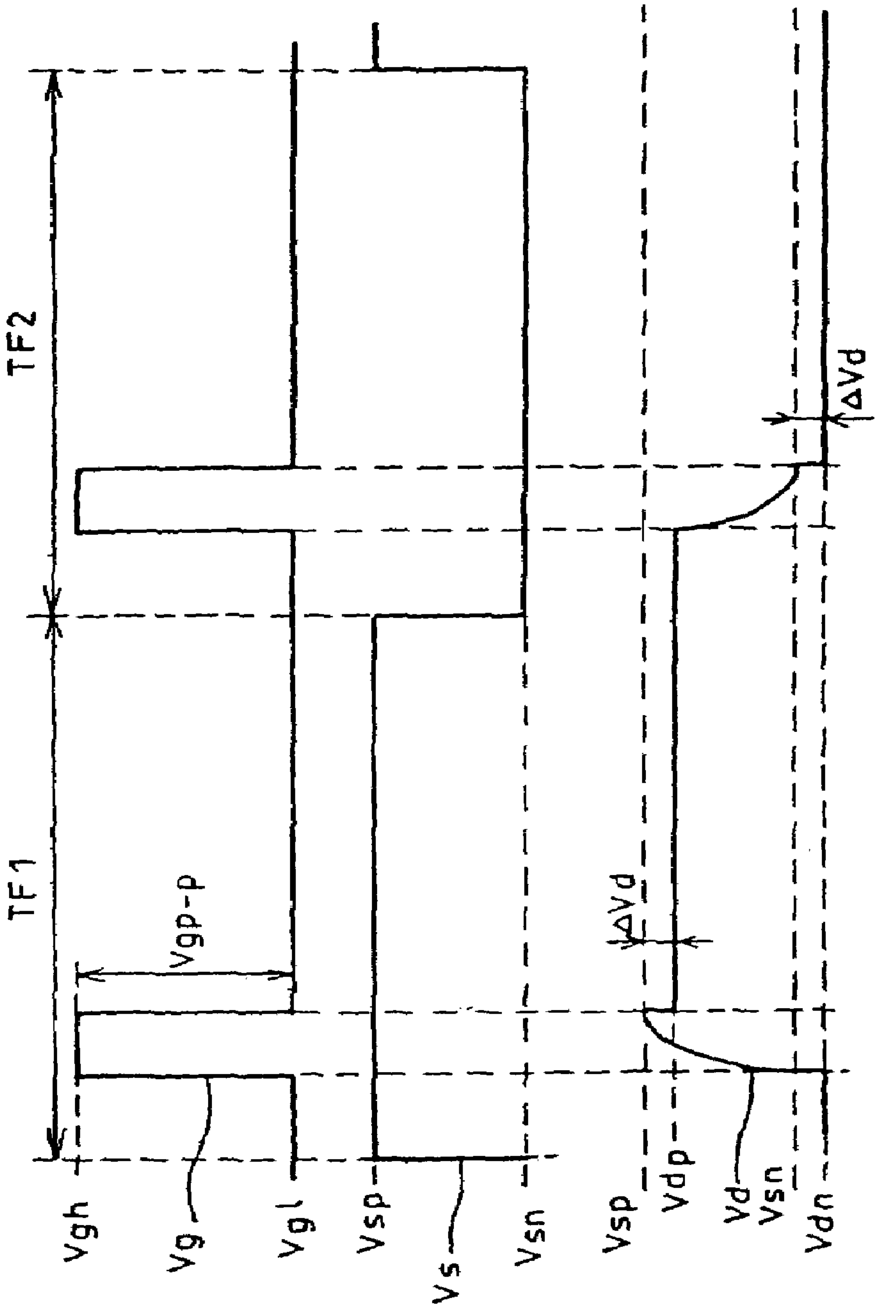


FIG.13

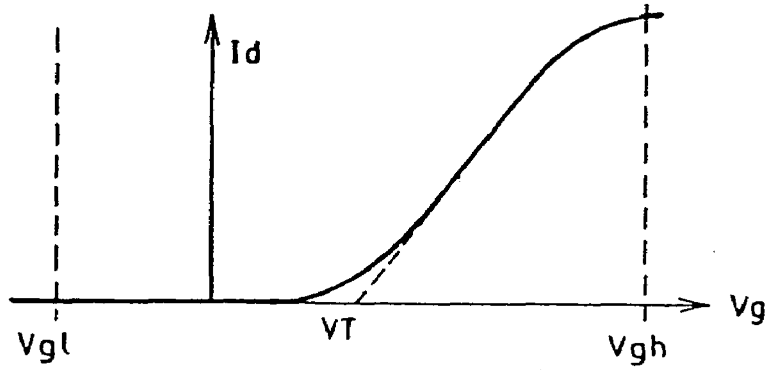

Id
Vg
Vgl
VT
Vgh

FIG.14

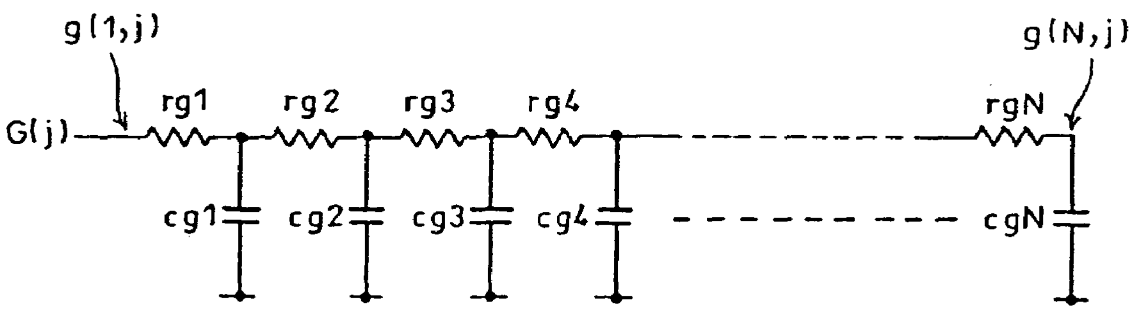
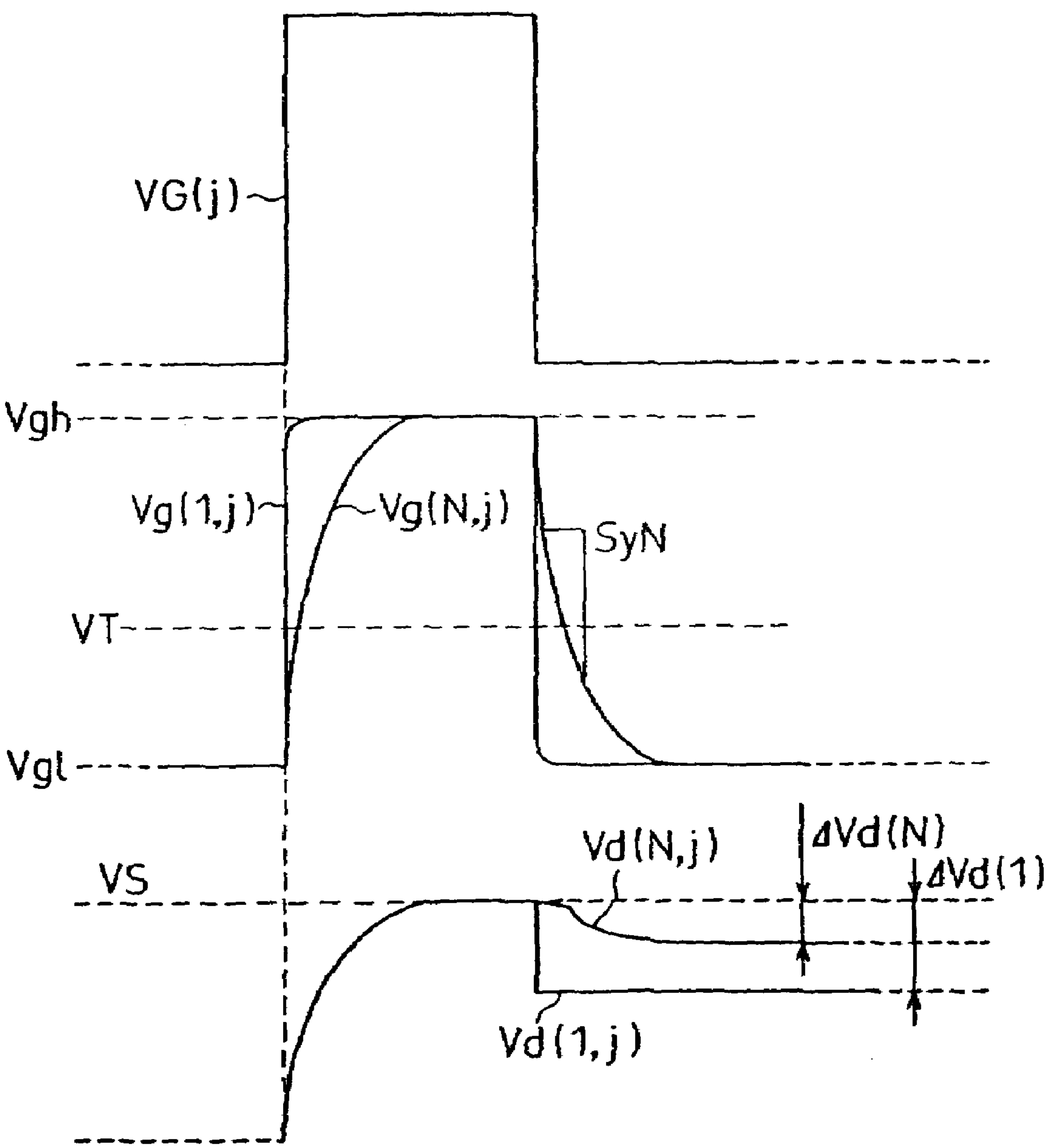

g(1,j)
g(N,j)
G(j)
rg1
rg2
rg3
rg4
rgN
cg1
cg2
cg3
cg4
cgN

FIG. 15



DISPLAY DEVICE AND DISPLAY METHOD

This application is a Divisional of application Ser. No. 10/883,375, filed Jun. 30, 2004 (now U.S. Pat. No. 7,027, 024), which is a Continuation of application Ser. No. 10/037, 804, filed Dec. 26, 2001 (now U.S. Pat. No. 6,867,760), which is a Divisional of application Ser. No. 09/275,063, filed Mar. 23, 1999 (now U.S. Pat. No. 6,359,607), the entire contents of which are hereby incorporated herein by reference in this application.

FIELD OF THE INVENTION

The present invention relates to a display device such as a matrix-type liquid crystal display (LCD) device and a display method thereof, and particularly relates to a display device such as an LCD device in which each display pixel is equipped with, for example, a thin film transistor as a switching element, and a display method thereof.

BACKGROUND OF THE INVENTION

LCD devices are widely used as display devices for use in TVs, graphic displays, and the like. Among these, attracting considerable attention are LCD devices in which each display pixel is equipped with a thin film transistor (hereinafter referred to as TFT) as a switching element, since such LCD devices produce display images which undergo no crosstalk between adjacent display pixels even in the case where display pixels therein increase in number.

Such an LCD device includes as main components an LCD panel **1** and a driving circuit section as shown in FIG. **9**, and the LCD panel is formed by sealing liquid crystal composition between a pair of electrode substrates and applying deflecting plates onto outer surfaces of the electrode substrates.

A TFT array substrate which is one of the electrode substrates is formed by laying a plurality of signal lines S(**1**), S(**2**), . . . S(i), . . . S(N) and a plurality of scanning signal lines G(**1**), G(**2**), . . . G(j), . . . G(M) in a matrix form on a transparent insulating substrate **100** made of glass, for example. At each intersection of the signal lines and the scanning signal lines, a switching element **102** composed of a TFT which is connected with a pixel electrode **103** is formed, and an alignment film is provided so as to cover almost all of them. Thus, the TFT array substrate is formed.

On the other hand, a counter substrate which is the other electrode substrate is formed by laminating a counter electrode **101** and an alignment film all over a transparent insulating substrate made of, for example, glass, as the TFT array substrate. The driving circuit section is composed of a scanning signal line driving circuit **300**, a signal line driving circuit **200**, and a counter electrode driving circuit COM, which are connected with the scanning lines, the signal lines, and the counter electrode of the LCD panel thus formed, respectively. A control circuit **600** is a circuit for controlling both the signal line driving circuit **200** and the scanning signal line driving circuit **300**.

The scanning signal line driving circuit (gate driver) **300** is composed of, for example, a shift register section **3***a* composed of M flip-flops cascaded, and selection switches **3***b* which are opened/closed in accordance with outputs of the flip-flops sent thereto, respectively, as shown in FIG. **10**.

An input terminal VD**1** out of two input terminals of each selection switch **3***b* is supplied with a gate-on voltage Vgh which is enough to cause the switching element **102** (see FIG. **9**) to attain an ON state, while the other input terminal

VD**2** thereof is supplied with a gate-off voltage Vgl which is enough to cause the switching element **102** to attain an OFF state. Therefore, gate start signals (GSP) are sequentially transferred through the flip-flops in response to a clock signal (GCK) and are sequentially outputted to the selection switches **3***b*. In response to this, each selection switch **3***b* selects the voltage Vgh for turning on the TFT and outputs it to the scanning signal line **105** during one scanning period (TH), and thereafter outputs the voltage Vgl for turning off the TFT to the scanning signal line **105**. With this operation, image signals outputted from the signal line driving circuit **200** to the respective signal lines **104** (see FIG. **9**) can be written in respective corresponding pixels.

FIG. **11** illustrates an equivalent circuit of a one display pixel P(i, j) in which a pixel capacitor Clc and a supplementary capacitor Cs are connected in parallel to a counter potential VCOM of the counter electrode driving circuit COM. In the figure, Cgd represents a parasitic capacitance between a gate and a drain.

FIG. **12** illustrates driving waveforms of a conventional LCD device. In FIG. **12**, Vg is a waveform of a signal for one scanning signal line, Vs is a waveform of a signal for one signal line, and Vd is a drain waveform.

Here, the following description will explain a conventional driving method, while referring to FIGS. **9**, **11**, and **12**. Incidentally, it is widely known that liquid crystal requires alternating current drive so as to avoid occurrence of burn-in residual images and deterioration of displayed images, and the conventional driving method described below is explained by taking as an example a frame inversion drive which is a sort of the alternating current drive.

When a scanning voltage Vgh is applied from the scanning signal line driving circuit **300** to a gate electrode g(i, j) (see FIG. **9**) of a TFT of one display pixel P(i, j) during a first field (TF**1**) as shown in FIG. **12**, the TFT attains an ON state, and an image signal voltage Vsp from the signal line driving circuit **200** is applied to a pixel electrode through a source electrode and a drain electrode of the TFT. Until a scanning voltage Vgh is applied during the next field (TF**2**), the pixel electrode maintains a pixel potential Vdp as shown in FIG. **12**. Since the counter electrode has a potential set to a predetermined counter potential VCOM by the counter electrode driving circuit COM, the liquid crystal composition held between the pixel electrode and the counter electrode responds in accordance with a potential difference between the pixel potential Vdp and the counter potential VCOM, whereby image display is carried out.

Likewise, when a scanning voltage Vgh is applied to a TFT gate electrode g(i, j) of one display pixel P(i, j) during the second field (TF**2**) from the scanning signal line driving circuit **300** as shown in FIG. **12**, the TFT attains an ON state and an image signal voltage Vsn from the signal line driving circuit **200** is written in the pixel electrode. The pixel electrode maintains a pixel potential Vdn, and the liquid crystal composition responds in accordance with a potential difference between the pixel potential Vdn and the counter potential VCOM, whereby image display is carried out while liquid crystal alternating current drive is realized.

Since a parasitic capacitance Cgd is unavoidably formed between the gate and the drain of the TFT out of structural necessity as shown in FIG. **11**, a level shift Vd caused by the parasitic capacitance Cgd occurs to the pixel potential Vd at a fall of the scanning voltage Vgh, as shown in FIG. **12**. Let a non-scanning voltage (a voltage when the TFT is in the OFF state) of the scanning signal be Vgl, and the level shift

Vd which thus occurs to the pixel potential Vd, caused by the parasitic capacitance Cgd which is unavoidably formed in the TFT, is expressed as:

$$Vd=Cgd(Vgh-Vgl)/(Clc+Cs+Cgd)$$

Since the level shift causes a problem such as flickering of an image and deterioration of display, this is not favorable at all to LCD devices, of which higher definition and higher performance are required.

Therefore, conventionally has been proposed such a measure that the counter potential VCOM of the counter electrode is preliminarily biased so that the level shift Vd caused by the parasitic capacitance Cgd decreases.

By the foregoing conventional technique, however, it is difficult to arrange the scanning signal lines G(**1**), G(**2**), . . . G(j), . . . G(M) in such an ideal form that the scanning signal lines do not undergo signal delay transmission, and hence the scanning signal lines thus arranged results in constituting a signal delay path which undergoes signal delay to some extent.

FIG. **14** is a transmission equivalent circuit diagram in the case where signal transmission delay of one scanning signal line G(j) is focused. In FIG. **14**, rg**1**, rg**2**, rg**3**, . . . rgN represent resistance components of wire materials forming the scanning signal lines and resistance components due to wire widths and wire lengths, mainly. cg**1**, cg**2**, cg**3**, . . . cgN represent various parasitic capacitances which are structurally capacitance-coupled with the scanning signal lines. The parasitic capacitances include cross capacitances which are generated at intersections of the scanning signal lines with the signal lines. Thus, the scanning signal lines constitute a signal delay transmission path of a distributed constant type.

FIG. **15** illustrates a state in which the scanning signal VG(j) supplied from the aforementioned scanning signal line driving circuit **300** to one scanning signal line dulls inside the panel due to the above-described signal delay transmission characteristic of the scanning signal line. In FIG. **15**, a waveform Vg(**1**, j) is a waveform of the signal in the vicinity of a TFT gate electrode g(**1**, j) immediately after the output thereof from the scanning signal line driving circuit **300**, and has substantially no dullness. In contrast, in the same figure, a waveform Vg(N, j) is a waveform of the signal in the vicinity of a TFT gate electrode g(N, j) at a farther end of the scanning signal line from the scanning signal line driving circuit **300**, and has dulled due to the signal transmission delay characteristic of the scanning signal line. Due to the dullness, a shift takes place, whose change rate per unit time is indicated by SyN in the figure.

Further, the TFT is not perfectly an ON/OFF switch, but has a V-I characteristic (gate voltage-drain currency characteristic) as shown in FIG. **13**. In FIG. **13**, a voltage applied to the TFT gate is plotted as the axis of abscissa, while a drain voltage is plotted as the axis of ordinate. Normally the scanning pulse is composed of two voltage levels, one being a voltage level Vgh which is enough to cause the TFT to attain an ON state, while the other being a voltage level Vgl which is enough to cause the TFT to attain an OFF state. There however also exists an intermediate ON region (linear region) between a threshold level VT of the TFT and the level Vgh as shown in the figure.

Since the scanning signal therefore has a sharp fall from the level Vgh to the level Vgl at a pixel having the gate electrode g(**1**, j), immediately behind the output side of the scanning signal line driving circuit **300** as shown in FIG. **15**, the characteristic in the linear region of the TFT does not influence the scanning signal there. As a result, the level shift Vd(**1**) which occurs to the pixel potential Vd(**1**, j) due to the parasitic capacitance Cgd can be approximated as follows:

$$Vd(1)=Cgd(Vgh-Vgl)/(Clc+Cs+Cgd)$$

On the other hand, at the pixel having the TFT gate electrode g(N, j) located in the vicinity of the farther end of the scanning signal line, the scanning signal has a dull fall. The characteristic of the linear region of the TFT therefore reversely affects, and this results in the following: the level shift which is to occur to the pixel potential Vd due to the parasitic capacitance Cgd does not occur during the fall of the scanning signal from the level Vgh to the TFT threshold level VT since the TFT maintains the intermediate ON state due to the linear state, whereas a level shift Vd(N) which is to occur to the pixel potential Vd(N, j) due to the parasitic capacitance Cgd occurs in a region in which the scanning signal further falls from the vicinity of the threshold level VT to the level Vgl. Therefore, the level shift Vd(N) becomes as follows:

$$Vd(N)<Cgd(Vgh-Vgl)/(Clc+Cs+Cgd)$$

Thus, Vd(**1**)>Vd(N) is satisfied.

As described above, the level shifts Vd occurring to the pixel potentials Vd due to the parasitic capacitances Cgd inside the panel is not uniform throughout the display plane, and it becomes more hardly negligible as the LCD device has a larger screen and becomes higher-definition. Accordingly the conventional scheme of biasing the counter voltage becomes incapable of absorbing differences in the level shifts throughout the display plane, thereby being incapable of conducting optimal alternating current drive with respect to each pixel. Consequently defects such as flickering and burn-in residual images due to DC component application are induced (see the Japanese Publication for Laid-Open Patent Application No. 120720/1995 (Tokukaihei 7-120720, date of publication: May 12, 1995)).

SUMMARY OF THE INVENTION

The present invention is made in light of the aforementioned problems of the prior art, and the object of the present invention is to provide a display device which is capable of sufficiently suppressing occurrence of flickering and the like which ensue to fluctuations of pixel potentials caused by parasitic capacitances, and which is high-definition and high-performance.

To achieve the foregoing object, a display device of the present invention comprises (1) a plurality of pixel electrodes, (2) image signal lines for supplying data signals to the pixel electrodes, (3) a plurality of scanning signal lines provided so as to intersect the image signal lines, and (4) a driving circuit for outputting a scanning signal to actuate the scanning signal lines, as well as (5) TFTs each having a gate, a source, and a drain which are connected with one scanning signal line, one image signal line, and one image electrode, respectively, the TFTs being provided at the intersections, respectively, and the display device is arranged so that the driving circuit controls falls of the scanning signal.

With the foregoing arrangement, the scanning signal is outputted to the scanning signal lines by the driving circuit, and in this outputting operation, the falls of the scanning signal are controlled by the driving circuit.

Generally, parasitic capacitances are unavoidably formed between the gate and the drain of the thin film transistor due to the structure. In the case where the scanning signal abruptly falls as in the conventional cases, the thin film transistor immediately attains an OFF state, and upon this, a

potential of a pixel electrode (hereinafter referred to as pixel potential) lowers by a quantity corresponding to a fall quantity of the scanning signal (a scanning voltage minus a non-scanning voltage) due to the parasitic capacitance, whereby a significant level shift occurs to the pixel potential. Such significant level shift occurring to the pixel potential leads to flickering of a displayed image, deterioration of display, and the like.

According to the foregoing display device, however, the falls of the scanning signal are controlled, and hence it is possible to control the scanning signal so that it does not abruptly fall. This ensures that the level shifts of the pixel potentials caused by the parasitic capacitances are reduced.

Further, wires laid on a transparent insulating substrate made of, for example, glass are not an ideal path but constitute a signal delay path which undergoes signal delay to some extent. Therefore, the foregoing arrangement ensures that irregularities of display caused by the signal delay are cancelled, and moreover, that the level shifts caused to the pixel potentials by the parasitic capacitances are made smaller and uniform. In result, displayed images of high performance can be obtained.

For a fuller understanding of the nature and advantages of the invention, reference should be made to the ensuing detailed description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a waveform chart illustrating waveforms outputted from components of a scanning signal line driving circuit in accordance with one embodiment of the present invention.

FIG. **2** is a waveform chart illustrating a scanning signal line waveform in the vicinity of an input-side end of a scanning signal line, a scanning signal line waveform in the vicinity of the other end of the scanning signal line, and respective pixel potentials.

FIG. **3** is an explanatory view illustrating an arrangement of a scanning signal line driving circuit in accordance with another embodiment of the present invention.

FIG. **4** is a block diagram illustrating an arrangement of a principal part of a scanning signal line driving circuit in accordance with still another embodiment of the present invention.

FIG. **5** is a waveform chart showing waveforms of main components in the arrangement shown in FIG. **4**.

FIG. **6** is a graph showing results of comparison between characteristics of a level shift caused by a parasitic capacitance Cgd in the case where the arrangement shown in FIG. **4** is applied to a 13.3-inch diagonal XGA (resolution: 1024 RGB 768) and those in the case of the prior art.

FIG. **7** is a circuit diagram illustrating an arrangement of a principal part of a scanning signal line driving circuit in accordance with still another embodiment of the present invention.

FIG. **8** is a waveform chart showing waveforms of main components in the arrangement shown in FIG. **7**.

FIG. **9** is an explanatory view illustrating an arrangement of a conventional liquid crystal display device.

FIG. **10** is an explanatory view illustrating an arrangement of a conventional scanning signal line driving circuit.

FIG. **11** is a equivalent circuit diagram of one display pixel which is arranged so that a pixel capacitor and a supplementary capacitor are connected in parallel to a counter potential of a counter electrode driving circuit.

FIG. **12** is a driving waveform chart of a conventional liquid crystal display device.

FIG. **13** is an explanatory view used in explanation of both the present invention and the prior art, which shows that a TFT is not perfectly an ON/OFF switch but has a linear gate voltage-drain currency characteristic.

FIG. **14** is a transmission equivalent circuit diagram in the case where signal transmission delay of one scanning signal line is focused.

FIG. **15** is an explanatory view illustrating a state in which a scanning signal supplied to a scanning signal line from the scanning signal linen driving circuit dulls inside the panel due to the signal delay transmission characteristic of the scanning signal line.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is made on the basis of the following: in a display device such as an LCD device, an input signal which varies without being affected by signal delay transmission characteristic which parasitically occurs is inputted to a wire laid on a transparent insulating substrate made of glass or the like, and by so doing, a waveform identical to a waveform of the input signal can be obtained at any position on a wire, while influences due to signal change can be made constant throughout the wire.

The present invention is also made on the basis of the following: depending on a ON/OFF characteristic of a switching element of a TFT or the like connected with the wire, a level shift caused by a parasitic capacitance can be reduced by making the input waveform and the waveform at a certain point of the wire dull.

First Embodiment

The following description will explain a first embodiment of the present invention while referring to FIGS. **1** and **2**. Note that in FIG. **1** GCK represents a clock signal.

FIGS. **1** and **2** show output waveforms VG(j−1), VG(j), and VG(j+1) of a scanning signal line driving circuit in accordance with the present embodiment, a scanning signal line waveform Vg(**1**, j) in the vicinity of an input-side end of a scanning signal line, a scanning signal line waveform Vg(N, j) in the vicinity of the other end of the scanning signal line, and respective pixel potentials Vd(**1**, j) and Vd(N, j) in the vicinity of the foregoing ends of the scanning signal line. In the output waveform VG(j) of the scanning signal line driving circuit, the fall from a scanning voltage Vgh to a non-scanning voltage Vgl is a fall at a slope (inclination) indicated by a change rate Sx, which is a change quantity per unit time, as shown in FIG. **1**.

The present embodiment has a display system in which data signals are supplied to a plurality of pixel electrodes through image signal lines while the pixel electrodes are actuated by supplying a scanning signal thereto through a scanning signal line which intersects the image signal lines. In this system, fall of the scanning signal is controlled during the actuation, and control of this fall is enabled by setting the change rate Sx desirably.

Thus, by appropriately setting the change rate Sx, a change rate Sx**1** of a fall waveform in the vicinity of the input-side end of the scanning signal line, and a change rate SxN of a fall waveform in the vicinity of the other end of the scanning signal line, become substantially equal, not being affected by signal delay transmission characteristic which the scanning signal line parasitically possesses, like the

scanning signal line waveforms Vg(**1**, j) and Vg(N, j) (see FIGS. **1** and **2**). This causes level shifts occurring to the pixel potentials Vd due to parasitic capacitances Cgd which parasitically exist in the scanning signal line to become substantially uniform throughout a display plane. In result, by applying a conventional scheme of biasing a counter potential VCOM so as to preliminarily reduce the level shifts Vd occurring to the pixel potentials Vd due to parasitic capacitances Cgd which parasitically exist in the scanning signal line, or the like, a display device in which flickering can be sufficiently reduced and which do not undergo defects such as burn-in residual images can be realized.

To make the change rates Sx**1** and SxN of the fall waveforms substantially equal irrelevant to their positions on the scanning line, control of the falls may be conducted on the basis of the signal delay transmission characteristic. Control in this manner enables to make the slopes of the scanning signal falls substantially equal wherever on the scanning line, thereby making level shifts of the pixel electrodes substantially equal.

Instead of the foregoing control of falls on the basis of the signal delay transmission characteristic, slopes of falls of the scanning signal may be controlled on the basis of a gate voltage-drain currency characteristic of the TFT. In the TFT, upon application of a voltage in a range of a threshold voltage to an ON voltage to the gate thereof, a drain currency (ON resistance) of the TFT, depending on a gate voltage, linearly varies. In other words, the TFT attains, not an ON state out of the binary states, but an intermediate ON state (in which the drain currency varies in an analog form in accordance with the gate voltage).

In this case, if the falls of the scanning signal are abrupt as in the conventional cases, level shifts of the pixel potentials caused by the parasitic capacitances occur as described above, irrelevant to the gate voltage-drain currency characteristic of the TFT. In the present embodiment, however, it is possible to control slopes of falls of the scanning signal so that the slopes are affected when the TFT is in the state of the foregoing linear variation (intermediate ON state). Since such control causes the fall of the scanning signal to become sloped while the TFT also linearly shifts from the ON state to the OFF state in accordance with the voltage-currency characteristic, each level shift of the pixel potential stemming from the parasitic capacitance is surely reduced.

It is more preferable to control the slopes of the falls of the scanning signal on the basis of both the signal delay transmission and the gate voltage-drain currency characteristic of the TFT. In this case, it is possible to make substantially equal the slopes of any falls of the scanning signals wherever on the scanning signal line. In result, the level shifts of the pixel potentials are made substantially equal to each other, while each level shift per se decreases.

Furthermore, the voltage level VT shown in FIG. **2** is a threshold voltage of the TFT shown in FIG. **13**, and since the TFT maintains the ON state during a time while the scanning signal falls from the scanning voltage Vgh to the threshold voltage VT, a level shift due to the parasitic capacitance Cgd hardly occurs during the foregoing time. On the other hand, there occurs a level shift due to a parasitic capacitance Cgd, influenced by a scanning signal line shift (VT-Vgl) which causes the TFT to attain the OFF state.

Since VT−Vgl<Vgh−Vgl is satisfied in the present embodiment, it is possible not only to cancel differences in the level shifts caused by parasitic capacitances throughout the display plane, but also to reduce each level shift per se caused by the parasitic capacitance Cgd.

Here, let a level shift caused by the parasitic capacitance Cgd to the pixel potential Vd of the pixel in the vicinity of an end of the scanning signal line on the side to the scanning signal line driving circuit of the prior art be Vd(**1**), while let a level shift occurring to the pixel at the other end thereof of the prior art be Vd(N), and further, let a level shift of the pixel potential Vd in the vicinity of an end of the scanning signal line on the side to the scanning signal line driving circuit of the present embodiment be Vdx(**1**), while let a level shift occurring to the pixel potential Vd at the other end thereof of the present embodiment be Vdx(N). In this case, since the change rates Sx**1** and SxN of the fall waveforms are substantially equal, not being affected by the signal delay transmission characteristic which the scanning signal line parasitically possesses as described above, the level shifts-occurring to the pixel potentials Vd due to the parasitic capacitances Cgd which parasitically exist become substantially uniform throughout the display plane, and satisfy the following relationship (see FIGS. **2** and **15**):

$$Vdx(1)=Vdx(N)<Vd(N)<Vd(1)$$

Accordingly, by applying the conventional scheme of biasing the counter potential VCOM of the counter electrode so that the level shifts stemming from the parasitic capacitances are preliminarily reduced, it is possible to provide a display device featuring lower bias level, less flickering and display defects such as burn-in residual images, and less power consumption.

Second Embodiment

The following description will explain a second embodiment of the present invention, while referring to FIG. **3**. For conveniences' sake, the members having the same structure (function) as those in FIG. **10** will be designated by the same reference numerals.

In the second embodiment of the present invention, as shown in FIG. **3**, as in the case of the conventional scanning signal line driving circuit shown in FIG. **10**, the scanning signal line driving circuit is composed of a shift register section **3***a* composed of M flip-flops (F**1**, F**2**, . . . , Fj, . . . , FM) cascaded, and selection switches **3***b* which are opened/closed in accordance with outputs from the flip-flops, respectively. An input terminal VD**1** out of two input terminals of each selection switch **3***b* is supplied with a gate-on voltage Vgh which is enough to cause the TFT to attain an ON state, while the other input terminal VD**2** thereof is supplied with a gate-off voltage Vgl which is enough to cause the TFT to attain an OFF state. A common terminal of each switch **3***b* is connected with the scanning signal line **105**.

Therefore, gate start signals (GSP) are sequentially transferred through the flip-flops in response to clock signals (GCK) and are sequentially outputted to the selection switches **3***b*. In response to this, during one scanning period (TH), each selection switch **3***b* selects the voltage Vgh for causing the TFT to attain the ON state and outputs it to the scanning signal line **105**, and thereafter selects the voltage Vgl for causing the TFT to attain the OFF state and outputs it to the scanning signal line **105**.

In the second embodiment, as shown in FIG. **3**, slew-rate (slue rate) control elements SC (slope control sections) which are capable of controlling fall rates of output signals (gate-off voltages Vgl) are added to the output stage of the conventional gate driver. With this arrangement, fall slopes of the scanning signals respectively outputted to the scanning signal lines can be controlled, as in the case shown in FIGS. **1** and **2**.

Each of the slew-rate control elements SC, which is provided between the selection switch **3***b* and the input terminal VD**2**, is equivalently an output impedance control element which controls impedance of each output of the gate driver, which increases output impedance only upon fall of the gate-off voltage outputted to the scanning signal line (the fall of the gate-off voltage is hereinafter referred to as “scanning signal line fall”), thereby to make the output waveform of the gate driver dull. This causes differences in fall speeds in the display panel, which stem from waveform dullness as transmission characteristics of the scanning signal lines, to cancel each other. In result, it is possible to suppress occurrence of the level shifts V due to influence of the aforementioned parasitic capacitances Cgd, while to make the level shifts throughout display panel equal to each other.

Incidentally, the slew-rate control element SC is not particularly limited, and it may be anything provided that it is capable of varying the output impedance so as to vary the fall speed. It may be realized by using, for example, a common control technique of adjusting impedance by controlling a gate voltage of a MOS transistor element.

Further, the output impedance is increased only upon the scanning signal line fall so that only the fall waveform is dulled in the present embodiment, but according to a panel structure used, the output impedance may, not being increased only upon the scanning signal line fall, but remain at an increased level unless another display defect such as crosstalk occurs with a high impedance during a time while the gate-off voltage Vgl is outputted after the scanning signal line fall.

Third Embodiment

As to the above-described second embodiment, a case where the slew-rate control element SC for controlling the fall speed (slope) of the scanning signal is added to the conventional structure of the scanning signal line driving circuit (gate driver) is explained. In this case, however, it is necessary to additionally provide the slew-rate control element SC in the gate driver, and the conventional common inexpensive gate driver cannot be applied as it is. Therefore, it is not economical.

In the third embodiment of the present invention, a conventional inexpensive common gate driver is used. This case will be explained below, with reference to FIGS. **4** and **5**.

The conventional gate driver is, as explained above with reference to FIG. **10**, arranged as follows: the gate-on voltage Vgh and the gate-off voltage Vgl are supplied thereto, and in response to the clock signal GCK, the gate driver outputs the scanning ON voltage Vgh to the scanning signal lines **105** sequentially, i.e., to one line during one scanning period (TH) selected, while outputs the voltage Vgl for causing the TFT to attain the OFF state to each scanning signal line **105** after the foregoing scanning period. On the other hand, in the present third embodiment, a circuitry as shown in FIG. **4** is adapted, whose output is used as the voltage Vgh of the scanning signal line driving circuit.

FIG. **4** shows a principal part of the scanning signal line driving circuit in accordance with the present embodiment, the principal part being composed of a resistor Rcnt and a capacitor Ccnt for electric charging and discharging respectively, an inverter INV for controlling the electric charging/discharging, and switches SW1 and SW2 for switching the electric charging/discharging.

A signal voltage Vdd is applied to one terminal of the switch SW**1**. The signal voltage Vdd is a direct current voltage which has a voltage level same as Vgh enough to cause the TFT to attain the ON state. The other terminal of the switch SW**1** is connected with one end of the resistor Rcnt, as well as with one terminal of the capacitor Ccnt. The other terminal of the resistor Rcnt is grounded via the switch SW**2**. Opening/closing control of the switch SW**2** is carried out according to a signal Stc (see FIG. **5**) which is supplied through the inverter INV. The signal Stc, generated by a control section which is not shown, synchronizes with each scanning period, and is also used in the opening/closing control of the switch SW**1**. The signal Stc is arranged so as to synchronize with the clock signal (GCK) as shown in FIG. **5**, and it may be produced, for example, by using a mono multivibrator (not shown).

Regarding opening/closing operations of the switches SW**1** and SW**2**, which will be described in more detail later, the switch SW**1** is closed when the signal Stc is at the high level, and here the switch SW**2** becomes opened since a low level voltage is applied thereto through the inverter INV. On the other hand, the switch SW**1** is opened when the signal Stc is at the low level (discharge control signal), and here the switch SW**2** becomes closed since a high level voltage is applied thereto through the inverter INV. In short, in the arrangement shown in FIG. **4**, the switches SW**1** and SW**2** are high (level)-active elements.

An output signal VD**1***a* produced by the foregoing circuit is sent to the input terminal VD**1** of the scanning signal line driving circuit **300** shown in FIG. **10**. The signal Stc is a timing signal for use in control of a gate fall (scanning signal fall) time as shown in FIG. **5**, which synchronizes with each scanning period (TH).

With the foregoing arrangement, while the signal Stc is at the high level, the switch SW**1** is closed while the switch SW**2** is opened, and the output signal VD**1***a* is outputted as a voltage of the level Vgh to the input terminal VD**1** of the scanning signal line driving circuit **300**. On the other hand, while the signal Stc is at the low level, the switch SW**1** is opened while the switch SW**2** is closed, and electric charges stored in the capacitor Ccnt are discharged through the resistor Rcnt, whereby the voltage level gradually lowers. In result, the output signal VD**1***a* has a serrature-like waveform as shown in FIG. **5** (this type of serrature-like waveform with voltage-unchanging portions intermittently appearing as shown in FIG. **5** is hereinafter referred to as intermittent-serrature-like waveform, while “serrature-like waveform” is meant to broadly indicate all types of waveforms in a serrature-like form, including those with no voltage-unchanging portions).

By sending the output signal VD**1***a* (see FIG. **5**) produced by the circuit shown in FIG. **4** to the input terminal VD**1** of the scanning signal line driving circuit **300**, it is possible to easily produce a waveform in which the scanning signal line fall is sloped, like the waveform VG(j) shown in FIG. **5**. A slope time of sloped fall of the waveform is adjusted by varying a low-level period of the signal Stc, and a slope quantity Vslope can be adjusted by varying a resistance of the resistor Rcnt and a capacitance of the capacitor Ccnt so that a time constant of the circuit is adjusted. Thus, they may be optimized for each display panel to be driven.

FIG. **6** shows measurement results of level shifts caused by parasitic capacitances Cgd depending on positions on the scanning signal line, in the case where the present embodiment is applied to a 13.3-inch diagonal XGA (resolution: 1024 RGB 768). The following is clear from FIG. **6**: with application of the present embodiment, biased distribution

(irregularities) of the level shifts Vd in the display panel were completely eliminated and degrees of the level shifts Vd per se lowered as well.

As shown in FIG. **5**, in the output waveform VG(j), the waveform of the fall is not necessarily sloped thoroughly from the level Vgh to the level Vgl. More specifically, FIG. **6** shows that the slope of the gate fall in an ON region of the TFT (namely, a region in which the output waveform VG(j) is in a range of the voltage Vgh to the threshold voltage) has a great significance in distribution of the level shifts Vd throughout the display plane. In other words, in the OFF region of the TFT, the level shifts Vd does not depend on the speed of the gate fall. Therefore, such a slight re-shaping of the fall waveform yields a sufficient effect.

Fourth Embodiment

In the aforementioned third embodiment, the fall speed of the scanning signal line fall is controlled by (i) adjusting the slope time of the scanning signal line fall by varying a low-level period of the signal Stc, and (ii) adjusting a slope quantity Vslope by varying a resistance of the resistor Rcnt and a capacitance of the capacitor Ccnt so that a time constant of the circuit is adjusted. In the case of a larger-size display device, electric charge held by a scanning signal line varies with parasitic capacitances at intersections of scanning signal lines and signal lines as well as with a display state, and moreover, in the case where the device adapts a scheme of natural discharge, the fall speed is unstable, whereby the display device is, far from achieving the object, prone to a new defect such as display noise. The present embodiment is to solve such inconveniences. The following description will explain details of the present embodiment.

FIG. **7** illustrates main components of a scanning signal line driving circuit in accordance with the present embodiment, and FIG. **8** illustrates waveforms of the main components. A signal Stc shown in FIG. **7** is a slope time control signal (charge control signal, and discharge control signal), and controls opening/closing of a switch SW**3** which is connected with a capacitor Cct in parallel. A constant currency source Ict is connected with an end of the capacitor Cct via a resistor Rct, and the other end of the capacitor Cct is grounded. A voltage Vct outputted from the capacitor Cct (potential difference between the both ends of the capacitor Cct) is sent to an inverting input terminal of an operational amplifier OP via a resistor R**3**. A resistor R**4** is connected between the inverting input terminal and an output terminal of the operational amplifier OP.

The signal Stc is arranged so as to synchronize with the clock signal (GCK) as shown in FIG. **5**, and it may be produced by using a mono multivibrator (not shown). The switch SW**3** is closed while the signal Stc is at the high level, and is opened while the signal Stc is at the low level.

On the other hand, a non-inverting input terminal of the operational amplifier OP is connected with an end of a resistor R**2** and an end of a resistor R**1**. The other end of the resistor R**2** is grounded, and a signal voltage Vdd is applied to the other end of the resistor R**1**. The signal voltage Vdd is a direct current voltage at a voltage level Vgh which is enough to cause the TFT to attain an ON state. An output signal VD**1***b* as a scanning signal is sent from an output terminal of the operational amplifier OP to an input terminal VD**1** of the scanning signal line driving circuit **300** shown in FIG. **10**.

The operational amplifier OP and the resistors R**1**, R**2**, R**3**, and R**4** constitute a differential amplifying circuit as a subtracting section. In the subtracting section, the following subtraction is conducted:

$$VD1b=Vdd(R2/(R1+R2))(1+(R4/R3))-(R4/R3)Vct$$

Here, let resistances of the resistors R**1**, R**2**, R**3**, and R**4** satisfy R**1**=R**4**, R**2**=R**3**, and A=R**4**/R**3**, and the following is satisfied:

$$VD1b=Vdd-A\ Vct$$

The following description will explain the operation of the circuit shown in FIG. **7**, while referring to FIG. **8**.

While the signal Stc outputted from a control section (not shown) is at the low level, the switch SW**3** is opened. In this state, power is supplied from the constant currency source Ict through the resistor Rct to the capacitor Cct, where electric charge is stored, and the voltage Vct has a serrature-like waveform as shown in FIG. **8**. In the subtracting section, the voltage Vct multiplied by A (=R**4**/R**3**) is subtracted from the signal voltage Vdd, and a resultant voltage is outputted as an output signal VD**1***b* (falling from the level Vgh by a slope quantity Vslope). Therefore, by varying A, it is possible to cause the output signal VD**1***b* to fall by a desirable slope quantity Vslope.

On the other hand, while the signal Stc is at the high level, the switch SW**3** is closed. Therefore, the electric charge stored in the capacitor Cct is discharged through the switch SW**3**, and the voltage outputted from the capacitor Cct becomes zero as shown in FIG. **8**. The subtracting section subtracts the voltage Vct multiplied by A (=R**4**/R**3**) from the signal voltage Vdd, but since the voltage Vct is zero, the signal voltage Vdd is outputted as the output signal VD**1***b* as shown in FIG. **8**.

As described above, with the control of the signal Stc, the voltage Vct has a serrature-like waveform with a maximum amplitude Vcth, and the output signal VD**1***b* has a waveform with a slope time Tslope and a slope quantity Vslope. The slope quantity Vslope satisfies:

$$Vslope=Vcth(R4/R3)$$

Therefore, the slope quantity can be easily adjusted by appropriately setting resistances of the resistors R**3** and R**4**. In addition, since the output signal VD**1***b* is an output of the operational amplifier OP, the impedance lowers (impedance when the operational amplifier is viewed from the next stage lowers).

By applying the present embodiment, therefore, it is possible to produce a scanning signal-use slope waveform with a fall characteristic optimal to any one of various LCD devices.

As to the display device of the present embodiment, for the same reason as that in the case of the display device of the third embodiment, there is no need to slope the waveform of each fall of the scanning signal thoroughly from the level Vgh to the level Vgl. Therefore, a minimum value of the output signal DV**1***b* is not necessarily lower than the threshold value of the TFT.

Incidentally, in the second through fourth embodiments, it is preferable that the falls are controlled on the basis of the signal delay transmission characteristic inherent in the scanning signal line, so that the change rates of the falls are equal wherever on the scanning signal line, as explained in the description of the first embodiment. Further, instead of controlling the falls on the basis of the signal delay transmission characteristic, the slopes of falls of the scanning signal may be controlled on the basis of the gate voltage-

drain currency characteristic of the TFT. Furthermore, it is more preferable to control the slopes of falls of the scanning signal based on both the signal delay transmission characteristic and the gate voltage-drain currency characteristic of the TFT.

As has been described above, the display device of the present invention is arranged so as to comprise (1) scanning signal lines, (2) TFTs each having a gate electrode connected with each scanning signal line, (3) image signal lines each of which is connected with a source electrode of each TFT, and (4) pixels each of which has (i) a pixel electrode connected with a drain electrode of the TFT, (ii) a supplemental capacitor element formed between the pixel electrode and the scanning signal line, and (iii) a liquid crystal capacitor element formed between the drain electrode and the counter electrode, and the display device is arranged so that transition from a scanning level to a non-scanning level of a write pulse on the scanning signal line has a certain slope and is gradual. In this case, the transition of the write pulse from the scanning level to the non-scanning level is desirably sloped by considering signal delay transmission characteristics of the scanning signal line.

In the foregoing display device, it is preferable that the transition of the write pulse from the scanning level to the non-scanning level has a desired gradual slope obtained by considering V-I characteristics of the TFTs.

Furthermore, in the foregoing arrangement, it is preferable that the transition of the write pulse from the scanning level to the non-scanning level has a gradual slope obtained by considering both the signal delay transmission characteristics of the scanning signal line and the V-I characteristics of the TFTs.

Another display device of the present invention is arranged so as to comprise (1) a plurality of pixel electrodes, (2) image signal lines for supplying data signals to the corresponding pixel electrodes respectively, (3) scanning signal lines which intersect the image signal lines, and (4) switching elements each of which is provided at each intersection of the image signal lines and the scanning signal lines, so that data signals are supplied to the pixel electrodes, respectively according to a scanning signal for controlling the switching elements, which is supplied to the scanning signal lines, and further, the display device is arranged so that transition from a scanning level to a non-scanning level on the scanning signal has a certain slope and is gradual.

Signal transmission paths from the scanning signal line driving circuit to the plurality of the switching elements preferably have signal delay transmission characteristics. It is preferable that the plurality of the switching elements do not have such switching characteristics as completely binary ON/OFF characteristics, but that an intermediate conductive state is exhibited.

Furthermore, still another display device of the present invention is arranged so as to comprise (1) a plurality of pixel electrodes, (2) image signal lines for supplying data signal to the corresponding pixel electrodes respectively, (3) scanning signal lines which intersect the image signal lines, (4) a scanning signal line driving circuit for driving the scanning signal lines, (5) TFTs each of which is provided at each intersection of the image signal lines and the scanning signal lines, and the display device is arranged so that the scanning signal line driving circuit which is capable of desirably adjusting a speed of output state transition of the scanning signal.

In this case, the speed of level changes of the scanning signal is preferably set by considering the signal delay transition characteristics of the scanning signal line. It is more preferable that the speed of level changes of the scanning signal is set by considering both the signal delay transmission characteristics of the scanning signal lines and the V-I characteristics of the TFTs.

Still another display device of the present invention is arranged so as to comprise (1) a plurality of pixel electrodes, (2) image signal lines for supplying data signal to the corresponding pixel electrodes respectively, (3) scanning signal lines which intersect the image signal lines, (4) a scanning signal line driving circuit for driving the scanning signal lines, (5) TFTs each of which is provided at each intersection of the image signal lines and the scanning signal lines, and the display device is arranged so that the voltage inputted to the scanning signal line driving circuit has a serrature-like waveform.

In this case, the voltage supplied to the scanning signal line driving circuit preferably has a intermittent-serrature-like waveform. A slope of the voltage of the serrature-like waveform is preferably set by considering the signal delay transmission characteristics of the scanning signal line. The slope of the voltage of the serrature-like waveform is preferably set by considering the V-I characteristics of the TFTs, and is more preferably set by considering both the signal delay transmission characteristics of the scanning signal lines and the V-I characteristics of the TFTs.

With the above-described present invention, regarding the fall waveforms of the scanning signal from the scanning signal line driving circuit, influences thereto of a scanning line to which the scanning signal is supplied are apparently smaller and speeds of the falls at respective positions of the scanning line are made uniform. This ensures that level shifts Vd occurring to the pixel potentials Vd due to parasitic capacitances Cgd are made uniform throughout the display plane.

Furthermore, since the fall waveforms of the scanning signal are dull, linear ON region characteristics of the TFTs are efficiently utilized, whereby the level shifts Vd occurring to the pixel potentials Vd due to parasitic capacitances Cgd per se are made smaller. As a result, the level shifts parasitically occurring to the pixel electrodes are made uniform and smaller throughout the display plane, and occurrence of flickering of images and occurrence of burn-in residual images can be sufficiently reduced, whereby high-definition and high-performance display devices can be obtained.

As described above, since the present invention ensures that the level shifts caused to pixel potentials by parasitic capacitances which are formed due to the structure are made uniform throughout the display plane, and/or that the level shifts per se are made smaller, it is possible to realize a display device which does not undergo flickering of images and defects such as burn-in residual images and which consumes less power. In other words, it is possible to realize a display device and a display method whose display performance and reliability are further improved. Thus, effects achieved by the present invention are remarkably significant.

Incidentally, as alternating current drive applicable to an LCD device, there have been proposed various schemes including the frame inversion drive in which a polarity of a signal line is switched every frame, the line inversion drive in which the polarity is switched every horizontal signal, and the dot inversion drive in which the polarity is switched every pixel. The present invention, however, does not depend on any one of these such driving schemes, but is effective for any driving scheme. (is efficiently applicable to not only these driving scheme but also any other driving scheme.

Furthermore, the display device of the present invention may be arranged so that the foregoing driving circuit controls the scanning signal based on the signal delay transmission characteristics inherent in the scanning signal lines, so that the scanning signal falls at a substantially same slope wherever on the scanning signal line.

With the foregoing invention, falls of the scanning signal are controlled by the driving circuit on the basis of the signal delay transmission characteristics of the scanning signal line. As a result of the control, the scanning signal falls at a substantially same slope wherever on the scanning signal line.

In the case where the scanning signal abruptly falls as in the conventional cases, the slope of the fall varies depending on positions on the scanning signal line because of the signal delay transmission characteristics inherent in the scanning signal lines. A level shift of a pixel potential in the vicinity of an input-side end of the scanning signal line at which the scanning signal abruptly falls is great, whereas a level shift of a pixel potential in the vicinity of the other end of the scanning signal line at which the scanning signal dully falls is small. Thus, generally the level shifts of pixel potentials are not uniform on the scanning signal line (in the display plane). The non-uniformity of the level shifts are not negligible in the case where the display device has a larger screen and in the case where high definition of images is required.

With the foregoing invention, however, it is possible to make slopes of falls of the scanning signal substantially uniform irrelevant to positions thereof on the scanning signal line. Therefore, the signal delay transmission characteristics inherent in the scanning signal lines can be neglected, and biased distribution of level shifts in the display plane does not occur. Thus, level shifts of the pixel potentials are made substantially uniform.

The display device of the present invention may be arranged so that the driving circuit controls the slopes of the falls of the scanning signal, based on gate voltage-drain currency characteristics of the TFTs.

With the foregoing invention, the slopes of falls of the scanning signal are controlled by the driving circuit on the basis of the voltage-currency characteristics of the TFTs.

Incidentally, the TFT attains transition to the ON state upon application of a threshold voltage to a gate thereof, and maintains the ON state stably upon application of a predetermined ON voltage which is higher than the threshold voltage, while attains transition to the OFF state when the gate voltage lowers to become not higher than the threshold voltage. Besides, when a voltage in a range of the threshold voltage to the ON voltage is applied to the gate, a drain currency (ON resistance) of the TFT linearly varies depending on the gate voltage (in other words, the TFT attains not the ON state out of the binary states, but an intermediate ON state (the drain currency varies in an analog form with the gate voltage)).

In the case where the falls of the scanning signal are abrupt as in the conventional cases, level shifts caused by parasitic capacitances occur to the pixel potentials as described above, irrelevant to the gate voltage-drain currency characteristics of the TFT.

With the foregoing invention, however, it is possible to control the slopes of falls of the scanning signal so that the slopes are influenced by the region of linear change of the TFT. By such control, the falls of the scanning signal slope, while the transition of the TFT from the ON state to the OFF state becomes linear transition on the basis of the voltage-currency characteristics. Therefore, the level shifts caused to the pixel potentials by parasitic capacitances are surely reduced.

As described above, at an initial stage of a fall of the scanning signal, the TFT is not yet in the OFF state but is in an intermediate ON state, in which a signal supplied from a source can be transmitted to the pixel electrode through the TFT and no level shift occurs to the pixel potential. Only at a latter stage of the fall of the scanning signal, a level shift occurs to the pixel potential, but the quantity thereof is small.

The display device of the present invention may be arranged so that the driving circuit controls slopes of falls of the scanning signal on the basis of both the signal delay transmission characteristics inherent in the scanning signal lines and the gate voltage-drain currency characteristics of the TFTs.

With the foregoing invention, it is possible to control the slopes of falls of the scanning signal, depending on the signal delay transmission characteristics inherent in the scanning signal lines and the linear region of the TFT. By such control, the falls of the scanning signal are sloped and transition of the TFT from the ON state to the OFF state becomes linear transition on the basis of the aforementioned voltage-currency characteristics. In result, level shifts caused by parasitic capacitances to the pixel potentials are surely reduced.

In other words, by the present invention, since the scanning signal is made to fall at a substantially same slope wherever on the scanning signal line, the level shifts of the pixel potentials become substantially uniform, while each level shift becomes smaller.

As described above, the level shifts of the pixel potentials occur only in association with a latter stage of each fall of the scanning signal, but each level shift is small and level shift distribution does not occur throughout the display plane.

The display device of the present invention may be further arranged so that the scanning signal is composed of a gate-on voltage which causes the TFT to attain an ON state and a gate-off voltage which causes the TFT to attain an OFF state, and that the driving circuit includes (1) a shift register section composed of a plurality of flip-flops which are cascaded and to which a scanning timing control signal is supplied, (2) slope control sections for controlling the slopes of the falls from the gate-on voltage to the gate-off voltage, and (3) switch sections each of which switches the gate-on voltage for the gate-off voltage or vice versa according to an output of each flip-flop.

According to the foregoing invention, when a scanning timing control signal is supplied to the shift register, a signal for switching signals is outputted from each flip-flop in response to a predetermined clock signal. The switch sections switch the gate-on voltage for the gate-off voltage or vice versa according to the signal outputted by each flip-flop and output the voltage, and here, the gate-off voltage is outputted from the switch sections after its fall is controlled by the slope control sections. Thus, by the foregoing invention, only by adding the slope control sections to the conventional driving circuit (gate driver), the slopes of the falls of the gate-off voltage are controlled on the basis of the signal delay transmission characteristics and/or the gate voltage-drain currency characteristics of the TFTs.

The display device of the present invention may be further arranged so that the scanning signal is composed of a gate-on voltage which causes the TFT to attain an ON state and a gate-off voltage which causes the TFT to attain an OFF

state, and that the driving circuit includes (1) a control section for outputting a discharge control signal which synchronizes with each scanning period, and (2) a driving voltage generating section which usually generates the gate-on voltage, and discharges the gate-on voltage in response to the discharge control signal.

According to the foregoing invention, the gate-on voltage is generated and controlled in the following manner. The discharge control signal which synchronizes with each scanning period is sent to the driving voltage generating section by the control section. Normally (in the case where the discharge control signal is non-active), the gate-on voltage is generated. When the gate-on voltage is applied to the scanning signal line, the TFT attains an ON state.

On the other hand, in response to the discharge control signal, the driving voltage generating section discharges the gate-on voltage during the period while the discharge control signal is received. With the discharge, the gate-on voltage lowers.

By thus controlling the timing and quantity of discharge during each scanning period, it is possible to output the scanning signal with a desirable fall slope.

The display device of the present invention may be further arranged so that the scanning signal is composed of a gate-on voltage which causes the TFT to attain an ON state and a gate-off voltage which causes the TFT to attain an OFF state, and that the driving circuit includes (1) a control section which outputs a charge control signal and a discharge control signal, which both synchronize with each scanning period, (2) a slope voltage control section which charges up in response to the charge control signal and outputs a slope control voltage, while makes the slope control voltage zero by discharging in response to the discharge control signal, and (3) a subtracting section which outputs a voltage resulting on subtraction of the slope control voltage from the gate-on voltage during the charging, while outputs the gate-on voltage during the discharge.

According to the foregoing invention, the gate-on voltage as the scanning signal is produced and controlled in the following manner. The charge control signal and the discharge control signal which synchronizes with each scanning period are outputted by the control section to the slope voltage control section. In response to the discharge control signal, the slope voltage control section suspends the charging operation, and makes the slope control voltage zero by discharging. With the discharge, the gate-on voltage, without being subject to subtraction, is applied from the subtracting section to the scanning signal line, and the TFT attains the ON state.

On the other hand, in response to the charge control signal, the slope voltage control section conducts the charging operation until receiving the discharge control signal, and outputs the slope control voltage to the subtracting section. With the charge, a result of subtraction of the slope control voltage from the gate-on voltage is applied from the subtracting section to the scanning signal line. With this application, the scanning signal becomes smaller than the threshold voltage, and the TFT attains the OFF state.

By thus controlling the timing and quantity of discharge during each scanning period, it is possible to output the scanning signal with a desirable fall slope.

The display method of the present invention, wherein a scanning signal is supplied through scanning signal lines which intersect the image signal lines and actuate the pixel electrodes so as to realize display, is arranged so that during the actuation falls of the scanning signal are controlled.

According to the foregoing invention, the scanning signal is outputted to the scanning signal lines so as to actuate the pixel electrodes, and during this operation, the falls of the scanning signal are controlled.

Generally, parasitic capacitances affect the actuation. In the case where the scanning signal abruptly falls as in the conventional cases, the TFT immediately attains an OFF state, and upon this, a pixel potential lowers by a quantity corresponding to a fall quantity of the scanning signal (a scanning voltage minus a non-scanning voltage) due to the parasitic capacitance, whereby a level shift occurs to the pixel potential. Such level shift occurring to the pixel potential leads to flickering of a displayed image, deterioration of display, and the like.

According to the foregoing display method, however, the falls of the scanning signal are controlled, and hence it is possible to control the scanning signal so that it does not abruptly fall. This ensures that the level shifts of the pixel potentials caused by the parasitic capacitances are reduced.

Furthermore, the display method of the present invention can be arranged so that during the actuation, the scanning signal is controlled on the basis of signal delay transmission characteristics inherent in the scanning signal lines, so that the scanning signal falls at a substantially same slope wherever on the scanning signal lines.

According to the foregoing invention, during the actuation, falls of the scanning signal are controlled on the basis of the signal delay transmission characteristics of the scanning signal lines. As a result of this control, the scanning signal falls at a substantially same slope irrelevant to positions on the scanning signal lines.

Generally, level shifts of pixel potentials are not uniform on the scanning signal lines (on the display plane). Such irregularities in the level shifts are not negligible when the LCD device is required to have a larger screen and to be high-definition.

However, according to the foregoing invention, the slopes of falls of the scanning signal are made uniform irrelevant to positions on the scanning signal lines, whereby the level shifts of the pixel potentials are made substantially uniform.

Furthermore, the display method of the present invention is arranged so that during the actuation, slopes of the falls of the scanning signal are controlled on the basis of gate voltage-drain currency characteristics of a plurality of TFTs provided at the intersections of the image signal lines and the scanning signal lines.

According to the foregoing invention, during the actuation, slopes of falls of the scanning signal are controlled on the basis of the voltage-currency characteristics of the TFTs.

Incidentally, the TFT attains transition to the ON state upon application of a threshold voltage to a gate thereof, and maintains the ON state stably upon application of a predetermined ON voltage which is higher than the threshold voltage, while attains transition to the OFF state when the gate voltage lowers to become not higher than the threshold voltage. Besides, when a voltage in a range of the threshold voltage to the ON voltage is applied to the gate, a drain currency (ON resistance) of the TFT linearly varies depending on the gate voltage (in other words, the TFT attains not the ON state out of the binary states, but an intermediate ON state (the drain currency varies in an analog form with the gate voltage)).

In the case where the falls of the scanning signal are abrupt as in the conventional cases, level shifts caused by parasitic capacitances occur to the pixel potentials as described above, irrelevant to the gate voltage-drain currency characteristics of the TFT.

With the foregoing invention, however, it is possible to control the slopes of falls of the scanning signal so that the slopes are influenced by the region of linear change of the TFT. By such control, the falls of the scanning signal slope, while the transition of the TFT from the ON state to the OFF state becomes linear transition on the basis of the voltage-currency characteristics. Therefore, the level shifts caused to the pixel potentials by parasitic capacitances are surely reduced.

Furthermore, the display method of the present invention can be arranged so that during the actuation, slopes of the falls of the scanning signal are controlled on the basis of both the signal delay transmission characteristics inherent in the scanning signal lines and the gate voltage-drain currency characteristics of a plurality of TFTs provided at the intersections of the image signal lines and the scanning signal lines.

With the foregoing arrangement, it is possible to control the slopes of falls of the scanning signal, depending on the signal delay transmission characteristics inherent in the scanning signal line and the linear region of the TFT. By such control, the falls of the scanning signal are sloped and transition of the TFT from the ON state to the OFF state becomes linear transition on the basis of the aforementioned voltage-currency characteristics. In result, level shifts caused by parasitic capacitances to the pixel potentials are surely reduced.

In other words, by the present invention, since the scanning signal is made to fall at a substantially same slope wherever on the scanning signal line, the level shifts of the pixel potentials become substantially uniform, while each level shift becomes smaller.

The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.

What is claimed is:

1. A display device comprising:

a plurality of pixels;

video signal lines for supplying data signals to the pixels;

scanning signal lines prepared by intersecting said video-signal lines;

a gate driver which outputs scanning signals to said scanning signal lines, and drives said scanning signal lines;

wherein a voltage level falls so that it may incline from a high level of said scanning signals to a middle level of the high level and a low level of said scanning signals, and it equips the exterior of said gate driver with the circuit which generates the waveform voltage which has a period accompanied by voltage-level change which goes up from this middle level to said high level after that, and

the voltage generated in said circuit is used in order to make a part of change between the high level and the low level of said scanning signal incline by being inputted into said gate driver.

2. The display device as set forth in claim **1**, wherein said gate driver supply said scanning signals by outputting the waveform for one period of said voltage to a scanning period, and outputting the voltage level below the fall termination level of said voltage-level change out of a scanning period to each scanning signal line.

3. The display device as set forth in claim **1**, wherein a period accompanied by said voltage-level change is the

period in which falls while a voltage level inclines from said direct current level after the period of direct current level.

4. The display device as set forth in claim **1**, wherein said circuit has the capacitor connected to the input of said gate driver, the voltage source connected to said input of said gate driver through the 1^{st} switch, and the resistance connected to said capacitor in parallel with through the 2^{nd} switch, and

a voltage of said capacitor of said circuit is inputted into said gate driver as the voltage of said waveform.

5. The display device as set forth in claim **1**, wherein said circuit has the operational amplifier by which a constant voltage is inputted into a non-inversed input terminal, the 1^{st} resistance connected to the inversed input terminal of said operational amplifier as input resistance, and the 2^{nd} resistance connected as feedback resistance between the output terminal of said operational amplifier, and the inversed input terminal;

a potential of the end of the opposite side of said inversed input terminal side of said 1^{st} resistance is a potential expressed with the sum of the period of fixed potential and the period of the potential which inclines and changes from the period of said fixed potential, and

an output voltage of said operational amplifier of said circuit is inputted into said gate driver as the voltage of said waveform.

6. The display device as set forth in claim **5**, wherein the end of the opposite side of said inversed input terminal side of said 1^{st} resistance is connected to the end of the parallel circuit of a switch and a capacitor, and concurrently, a constant current source passes constant current at said end of said parallel circuit, and thereby the potential of the end of the opposite side of said inversed input terminal side of said 1^{st} resistance is a potential expressed with the sum of the period of fixed potential and the period of the potential which inclines and changes from the period of said fixed potential.

7. A display device comprising:

a gate driver which outputs scanning signals to scanning lines and drives said scanning signal lines by using gate ON voltage and gate OFF voltage which are inputted into an input terminal for gate ON voltage, and an input terminal for gate OFF voltage, respectively, of the gate driver, wherein:

a voltage level changes so that it may incline from said gate ON voltage level to a middle level of said gate ON voltage level and gate OFF voltage level, and the exterior of said gate driver is provided with a circuit which generates a voltage with a waveform which has a period accompanied by voltage level change which changes from this middle level to said gate ON voltage level after that;

a voltage generated in said circuit is used in order to make at least a part of change between the gate ON voltage level and gate OFF voltage level of said scanning signal incline by being inputted into the input terminal for gate ON voltage of said gate driver.

8. The display device as set forth in claim **7**, wherein said gate driver outputs the voltage level inputted into a terminal for gate ON voltage to each scanning signal line during a period which the voltage level inputted into said input terminal for gate ON voltage changes from said gate ON voltage level to said middle level, and outputs after that the gate OFF voltage level inputted into said input terminal for gate OFF voltage.

9. The display device as set forth in claim **8**, wherein said gate driver outputs said inclining voltage level with a scan period to each scan signal line.

10. A display device comprising:
a plurality of pixels;
video signal lines for supplying data signals to the pixels;
scanning signal lines intersecting said video-signal lines;
a gate driver which outputs scanning signals to said scanning signal lines, and drives said scanning signal lines;
a circuit, which provides an input to the gate driver, that generates a waveform voltage that is provided to the gate driver, wherein the waveform voltage generated by said circuit is used in order to make at least part of a change between a high level and a low level of the scanning signal incline by being inputted into said gate driver; and
wherein the waveform voltage that is generated by said circuit and which is to be input to the gate driver includes a sloped portion which slopes downwardly in a sloped non-vertical manner from a first level to a second level, wherein the waveform voltage including the sloped portion thereof is input to the gate driver and causes the scanning signals output from the gate driver to include an inclined portion that inclines from a high level to a second level which is between the high level and a low level of the scanning signal.

11. The display device of claim **10**, wherein said circuit includes a discharge capacitor which is discharged in generating the waveform voltage that includes a sloped portion which slopes downwardly in the sloped non-vertical manner from the first level to the second level.

12. The display device of claim **11**, wherein the circuit includes a first switch provided between the discharge capacitor and a circuit input where a signal voltage Vdd is input to the circuit.

13. The display device of claim **11**, wherein the circuit comprises a switch provided between at least the discharge capacitor and an inverter.

14. The display device of claim **10**, wherein the circuit comprises a discharge capacitor and first and second switches.

15. The display device of claim **14**, wherein the circuit further comprises an inverter in communication with at least one of the switches.

16. The display device of claim **10**, wherein said circuit comprises: a capacitor connected to an input of said gate driver, wherein a voltage source is connected to said input of said gate driver and the capacitor through a 1^{st} switch, and a resistance electrically connected to said capacitor.

17. The display device of claim **10**, wherein the circuit receives a circuit input voltage having the first level, and the circuit comprises a first switch that selectively provides the circuit input voltage to a circuit output.

18. The display device of claim **17**, wherein the circuit comprises a capacitor which stores electric charges when the first switch in the circuit provides the circuit input voltage to the circuit output, and discharges the electric charges when the first switch stops providing the circuit input voltage to the circuit output.

19. The display device of claim **18**, wherein the first switch stops providing the circuit input voltage to the circuit output at a timing of the sloped portion of the waveform voltage.

20. The display device of claim **17**, wherein the first switch stops providing the circuit input voltage to the circuit output at a timing of the sloped portion of the waveform voltage.

21. The display device of claim **10**, wherein the circuit comprises a capacitor which stores electric charges when a first switch of the circuit provides a circuit input voltage to the circuit output and discharges the electric charges when the first switch stops providing the circuit input voltage.

* * * * *

EXHIBIT D

US007304703B1

(12) United States Patent
Takeda et al.

(10) Patent No.: US 7,304,703 B1
(45) Date of Patent: *Dec. 4, 2007

(54) VERTICALLY-ALIGNED (VA) LIQUID CRYSTAL DISPLAY DEVICE

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(73) Assignee: **Sharp Kabushiki Kaisha**, Osaka (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **09/663,580**

(22) Filed: **Sep. 15, 2000**

Related U.S. Application Data

(62) Division of application No. 09/097,027, filed on Jun. 12, 1998, now Pat. No. 6,724,452.

(30) **Foreign Application Priority Data**

Jun. 12, 1997	(JP)	9-155437
Aug. 27, 1997	(JP)	9-230982
Aug. 27, 1997	(JP)	9-230991
Sep. 30, 1997	(JP)	9-266937
Dec. 26, 1997	(JP)	9-361384

(51) **Int. Cl.**
G02F 1/1337 (2006.01)
G02F 1/1343 (2006.01)

(52) **U.S. Cl.** **349/129**; 349/130; 349/139

(58) **Field of Classification Search** 349/143, 349/144, 42, 43, 129–130, 138–139
See application file for complete search history.

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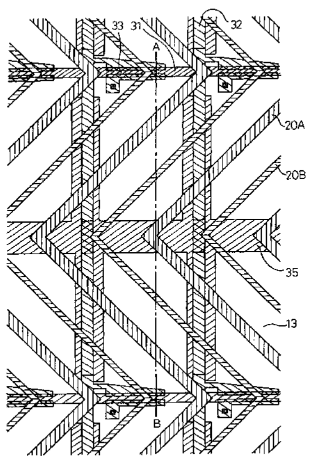

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Primary Examiner—Dung T Nguyen
(74) *Attorney, Agent, or Firm*—Greer, Burns & Crain, Ltd

(57) **ABSTRACT**

A vertically alignment mode liquid crystal display device having an improved viewing angle characteristic is disclosed. The disclosed liquid crystal display device uses a liquid crystal having a negative anisotropic dielectric constant, and orientations of the liquid crystal are vertical to substrates when no voltage being applied, almost horizontal when a predetermined voltage is applied, and oblique when an intermediate voltage is applied. At least one of the substrates includes a structure as domain regulating means, and inclined surfaces of the structure operate as a trigger to regulate azimuths of the oblique orientations of the liquid crystal when the intermediate voltage is applied.

23 Claims, 246 Drawing Sheets

Fig.1B
(PRIOR ART)

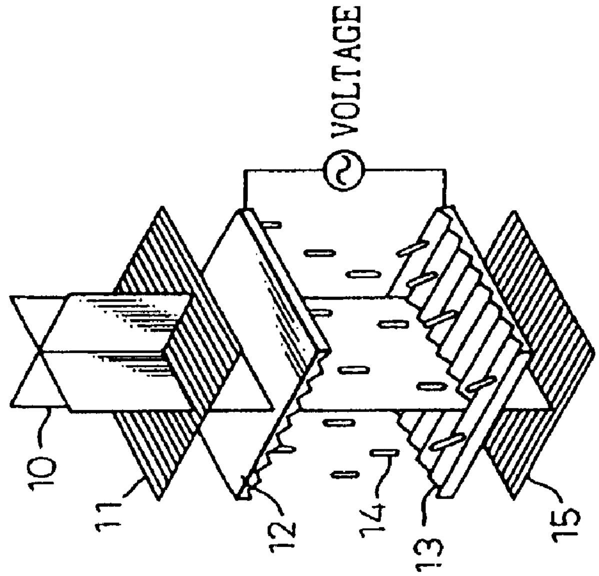

Fig.1A
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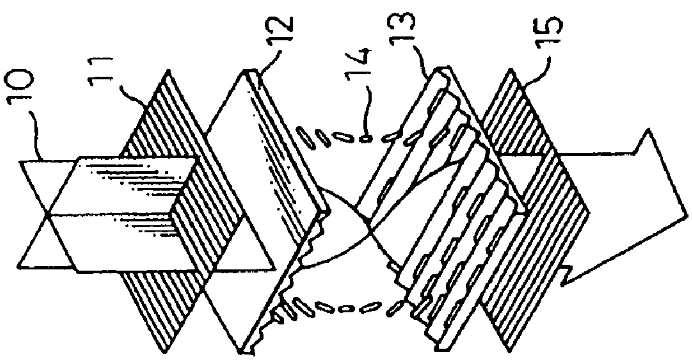

Fig. 2C
(PRIOR ART)

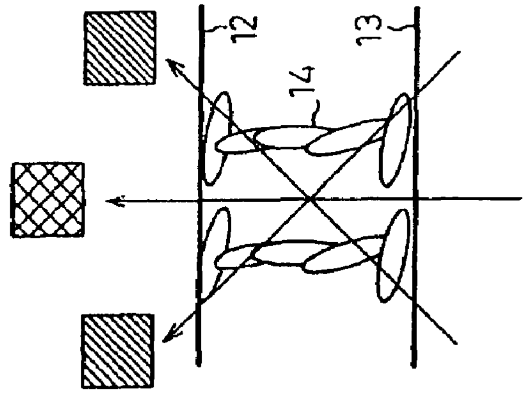

Fig. 2B
(PRIOR ART)

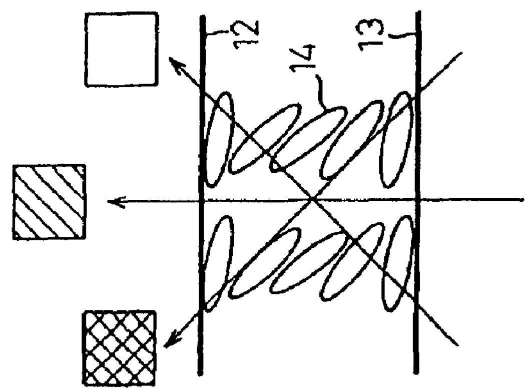

Fig. 2A
(PRIOR ART)

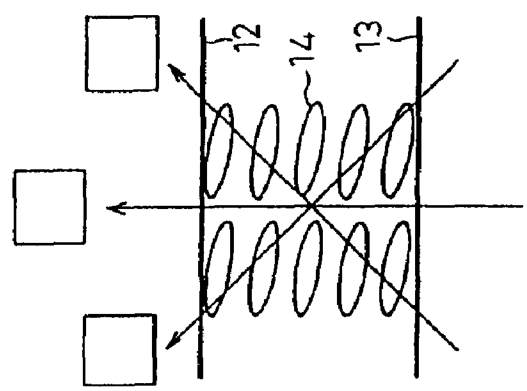

Fig.3A
(PRIOR ART)

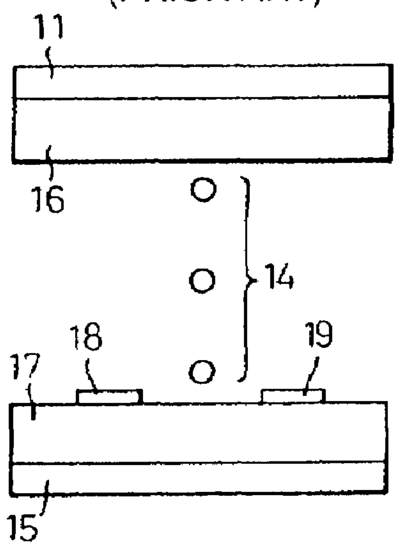

Fig.3C
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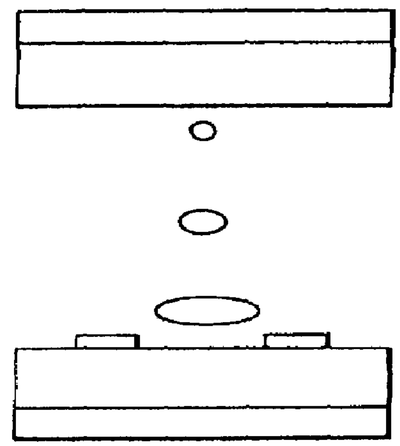

Fig.3B
(PRIOR ART)

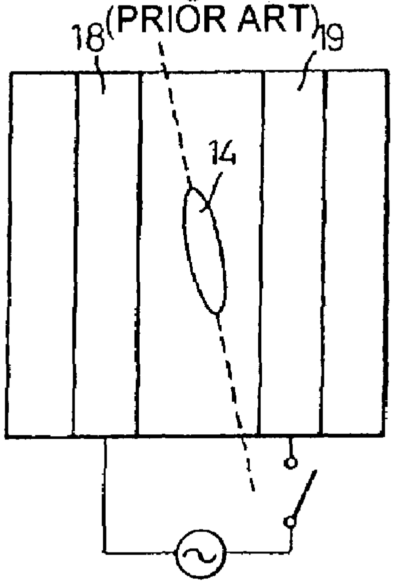

Fig.3D
(PRIOR ART)

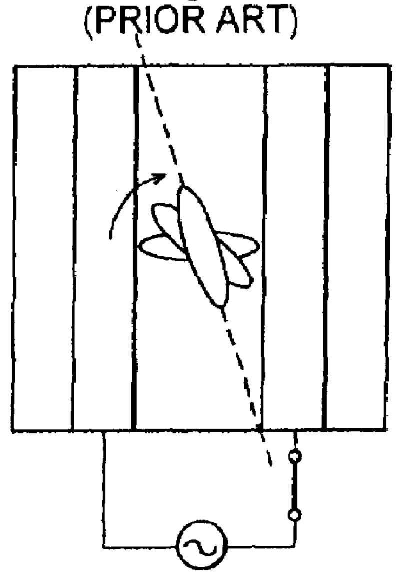

Fig.4
(PRIOR ART)

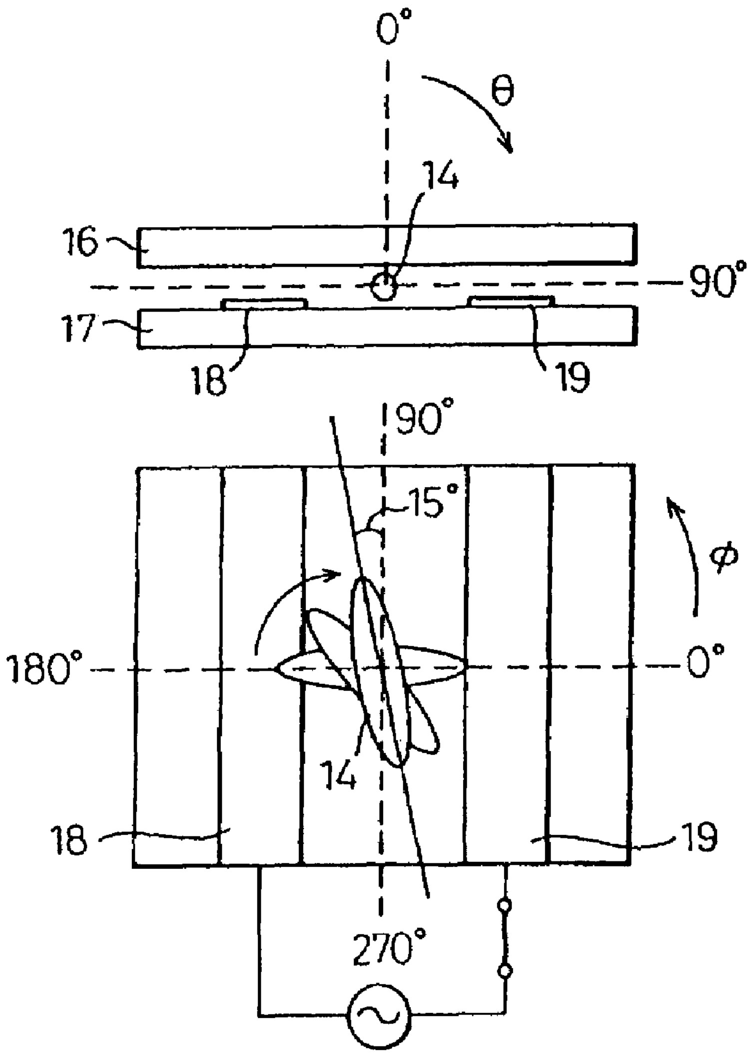

Fig.5
(PRIOR ART)

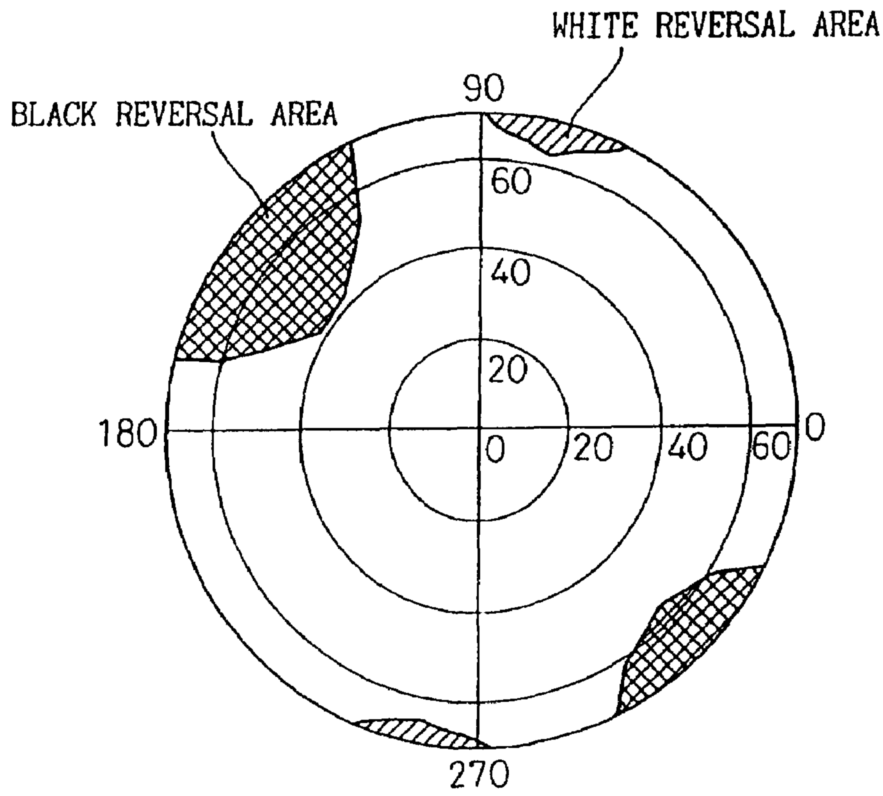

Fig. 6A
(PRIOR ART)

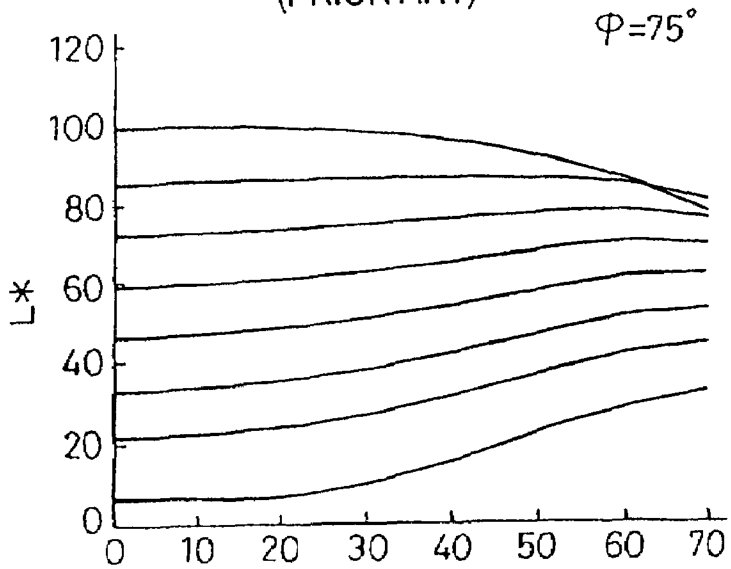

Fig. 6B
(PRIOR ART)

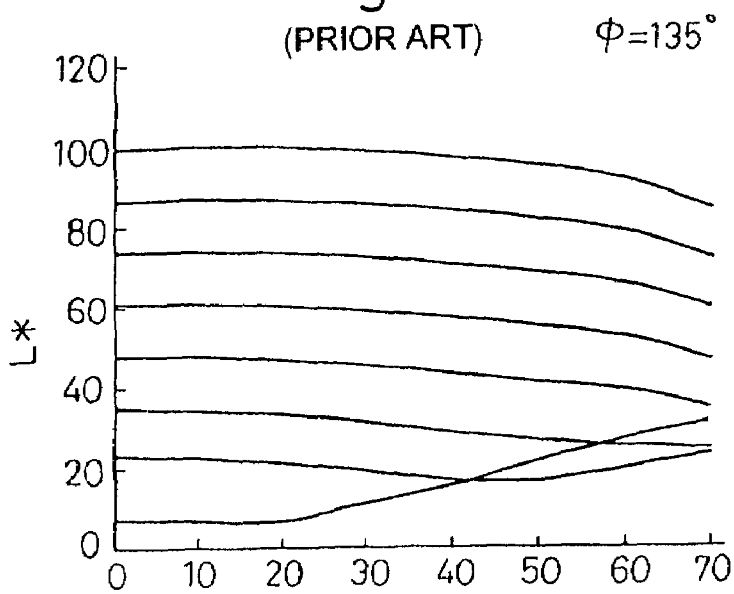

Fig.7C
(PRIOR ART)

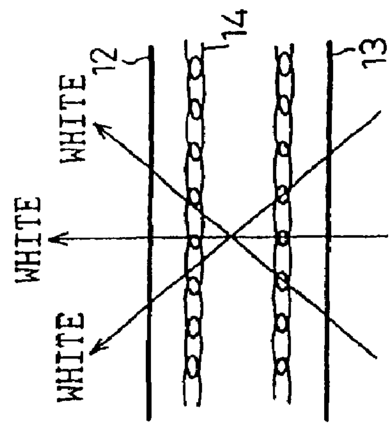

Fig.7B
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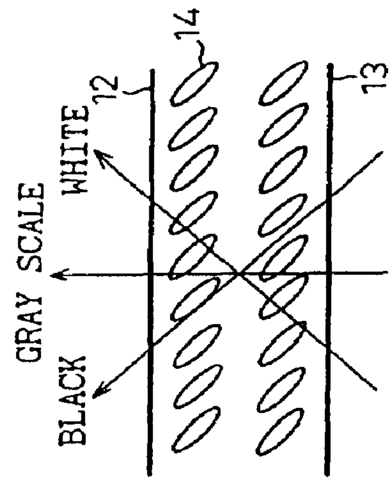


Fig.7A
(PRIOR ART)

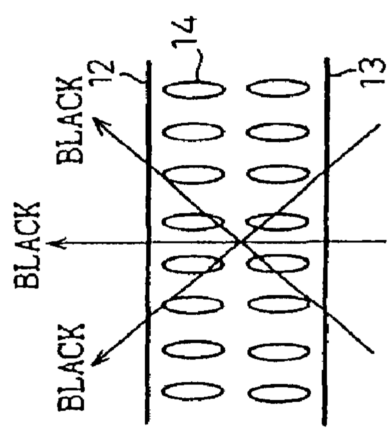


Fig.8A
(PRIOR ART)

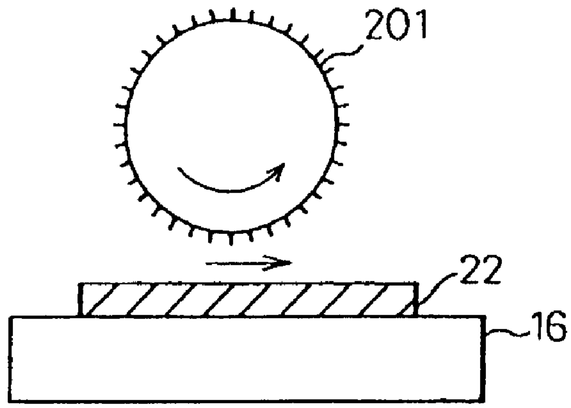


Fig.8B
(PRIOR ART)

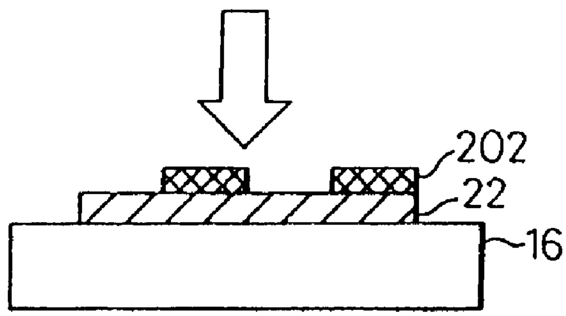


Fig.8C
(PRIOR ART)

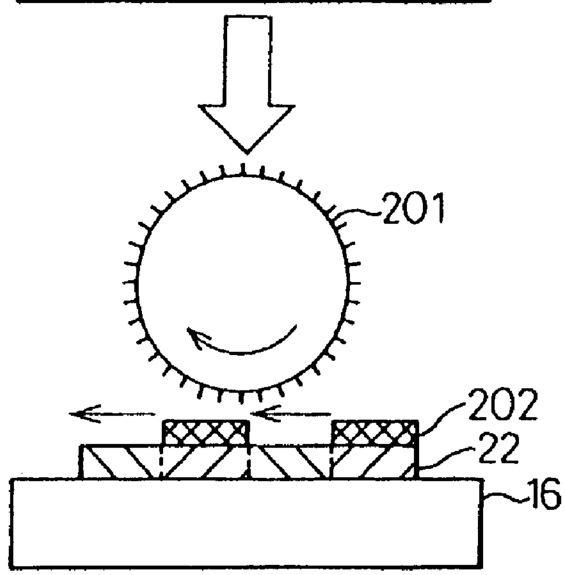


Fig.9C

Fig.9B

Fig.9A

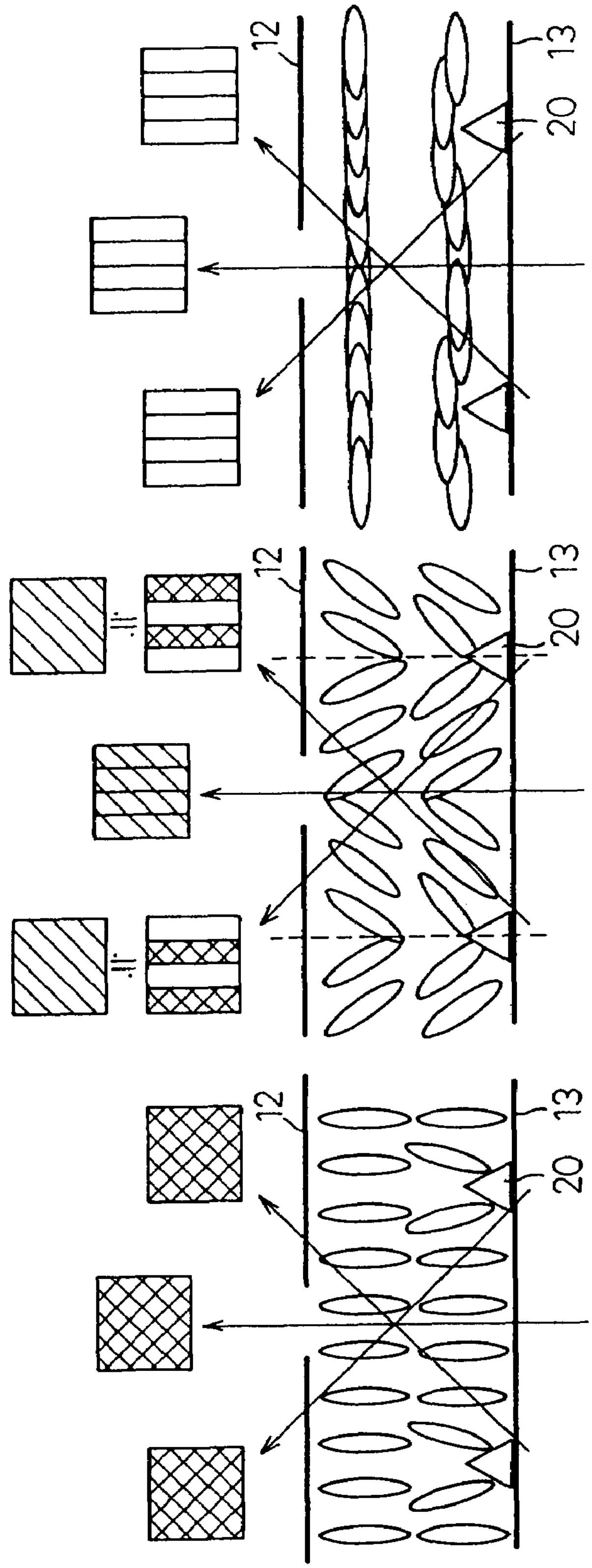


Fig.10A

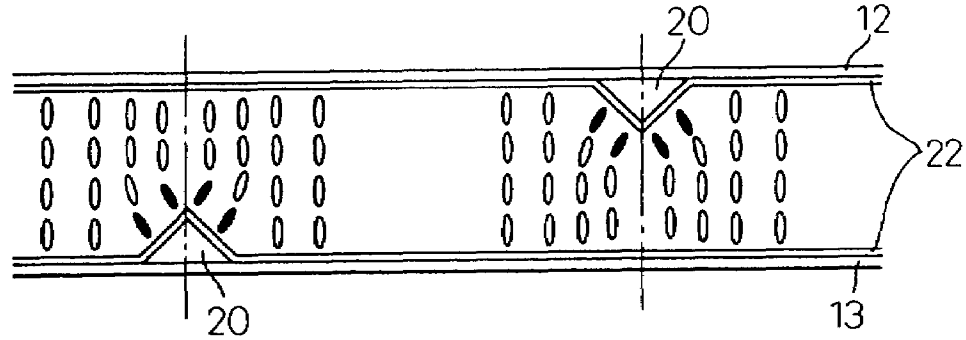


Fig.10B

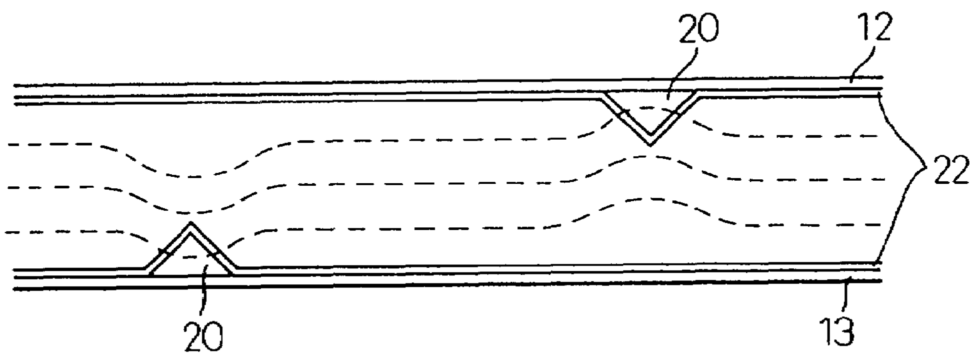


Fig.10C

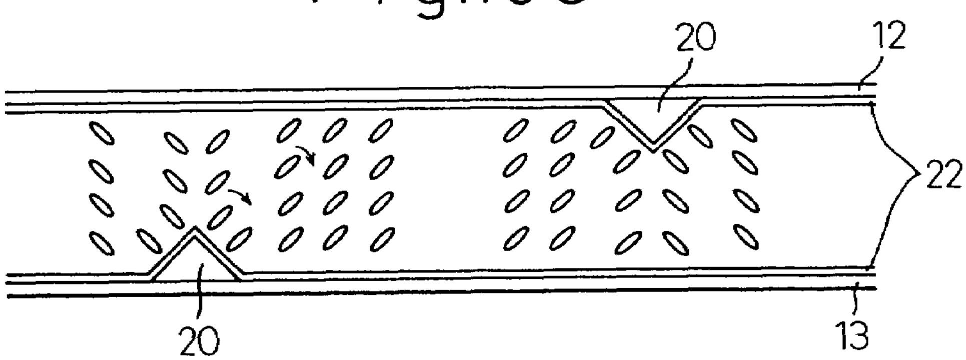


Fig.11A

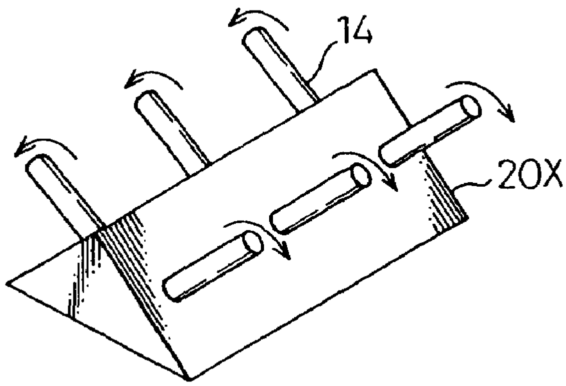


Fig.11B

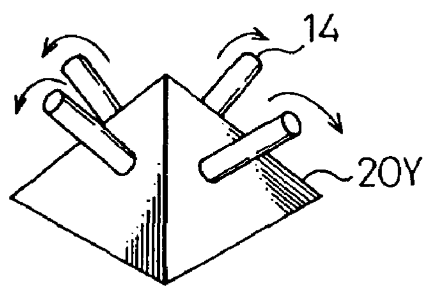


Fig.11C

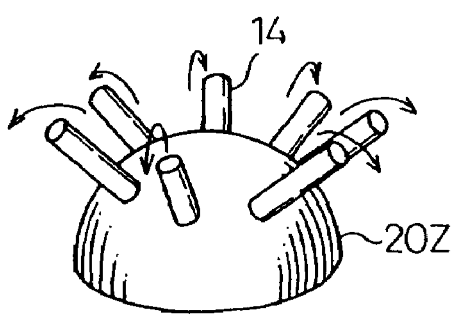


Fig.12A

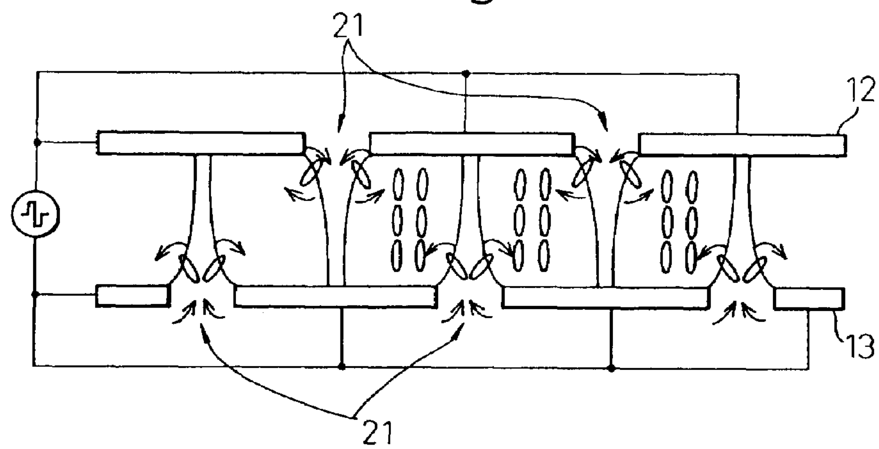


Fig.12B

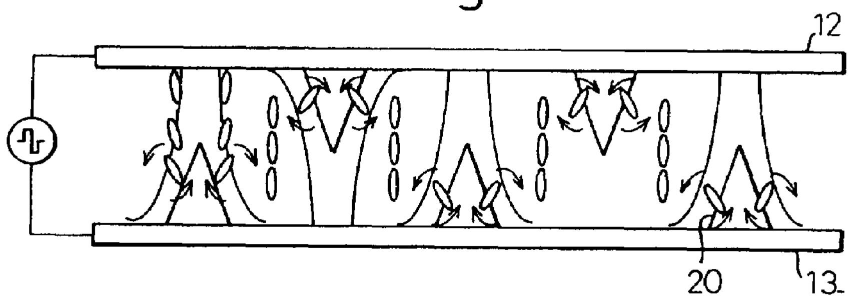


Fig.12C

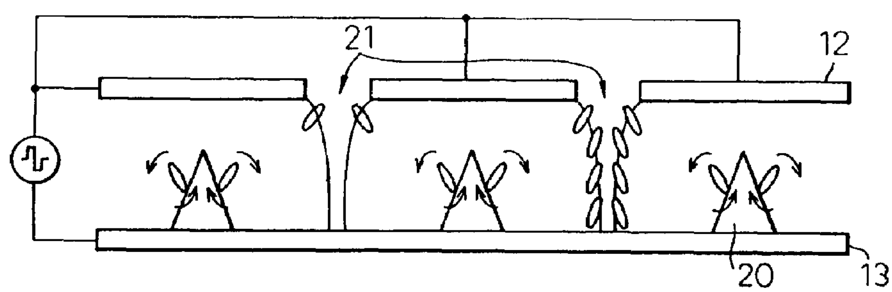


Fig.13

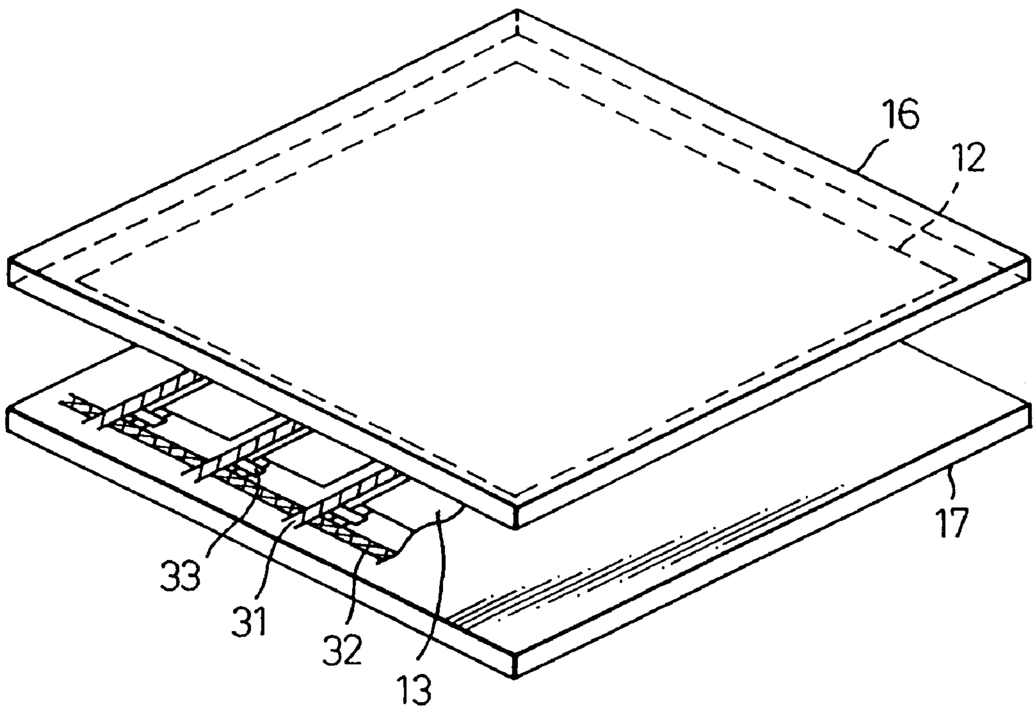


Fig.14A

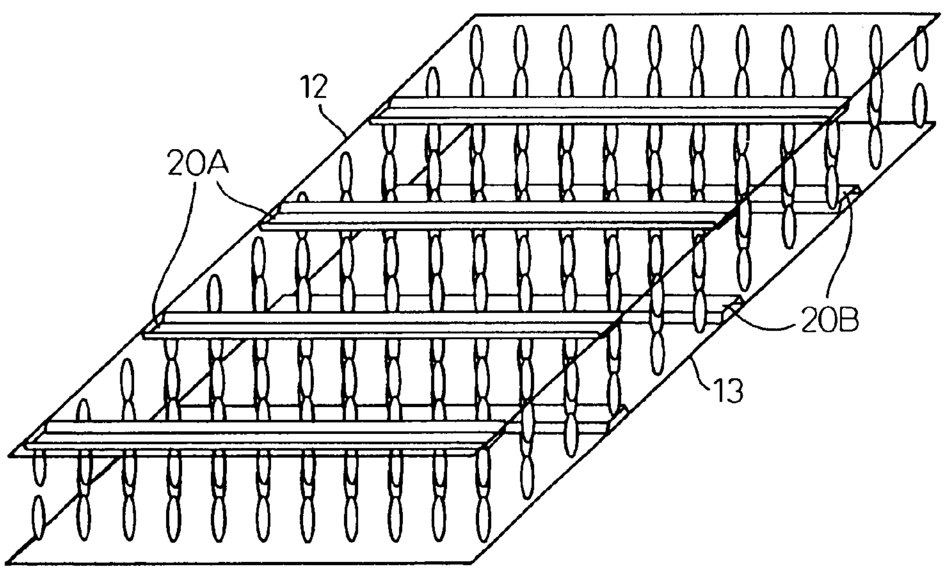


Fig.14B

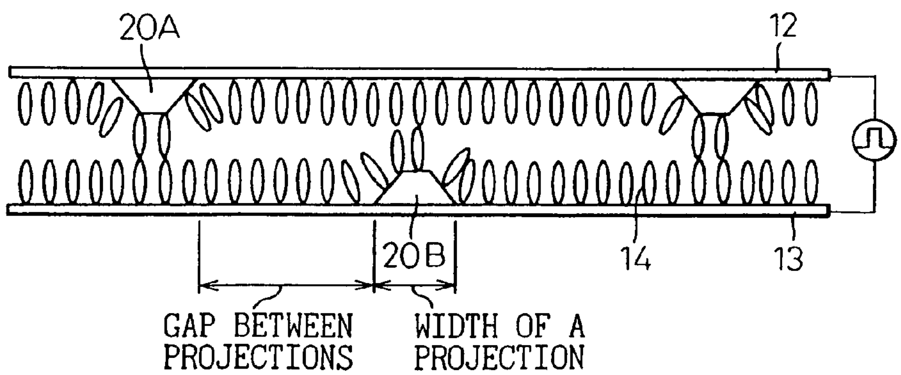


Fig.15

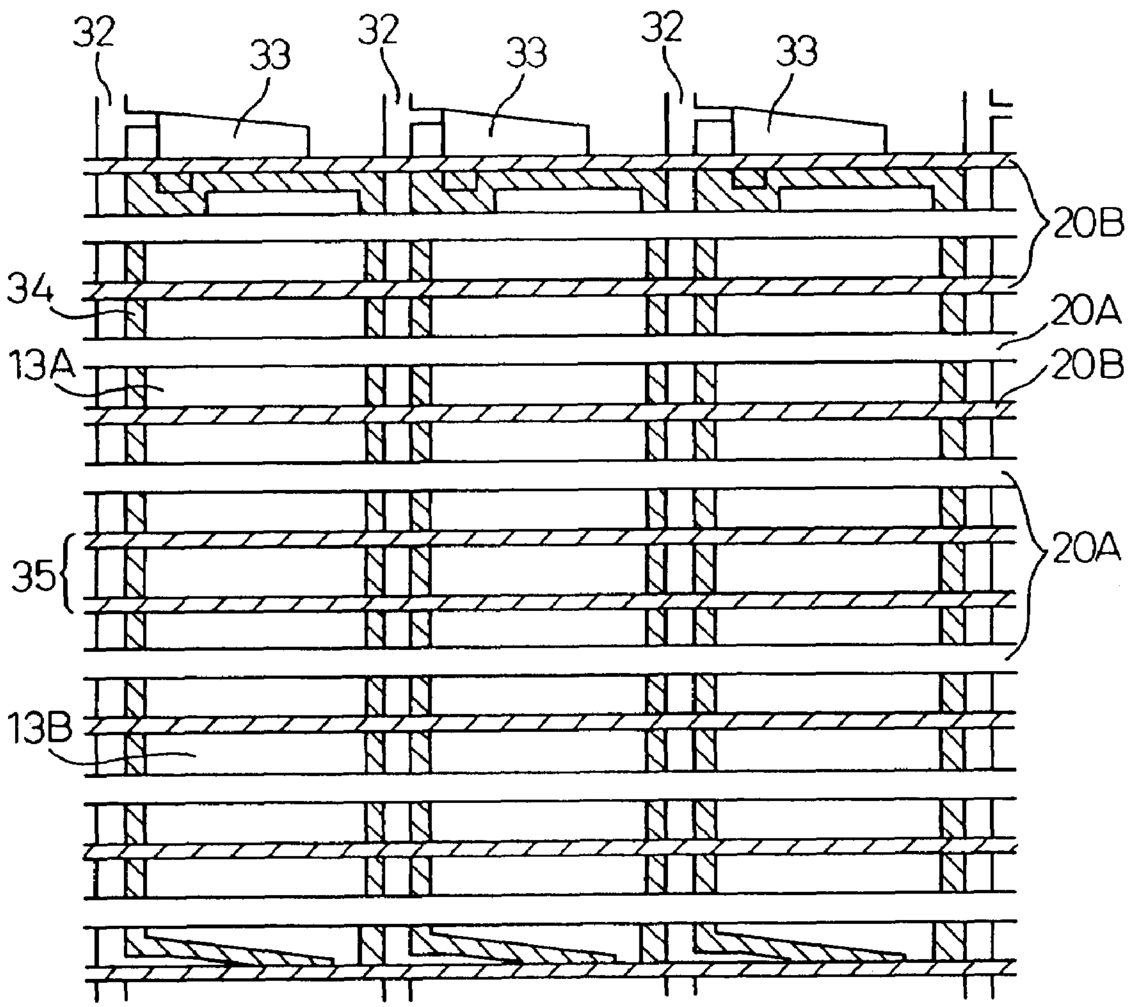
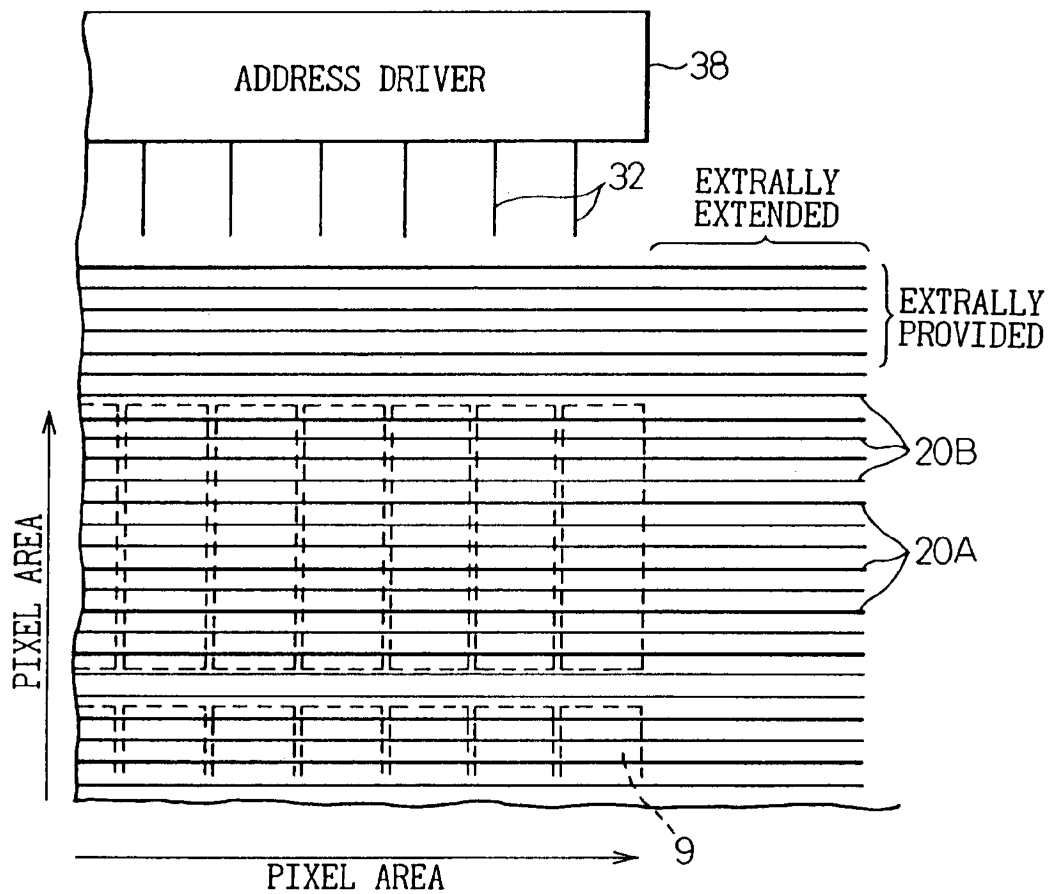


Fig.16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38
32
EXTRALLY EXTENDED
EXTRALLY PROVIDED
20B
20A
PIXEL AREA
PIXEL AREA
9

Fig.17

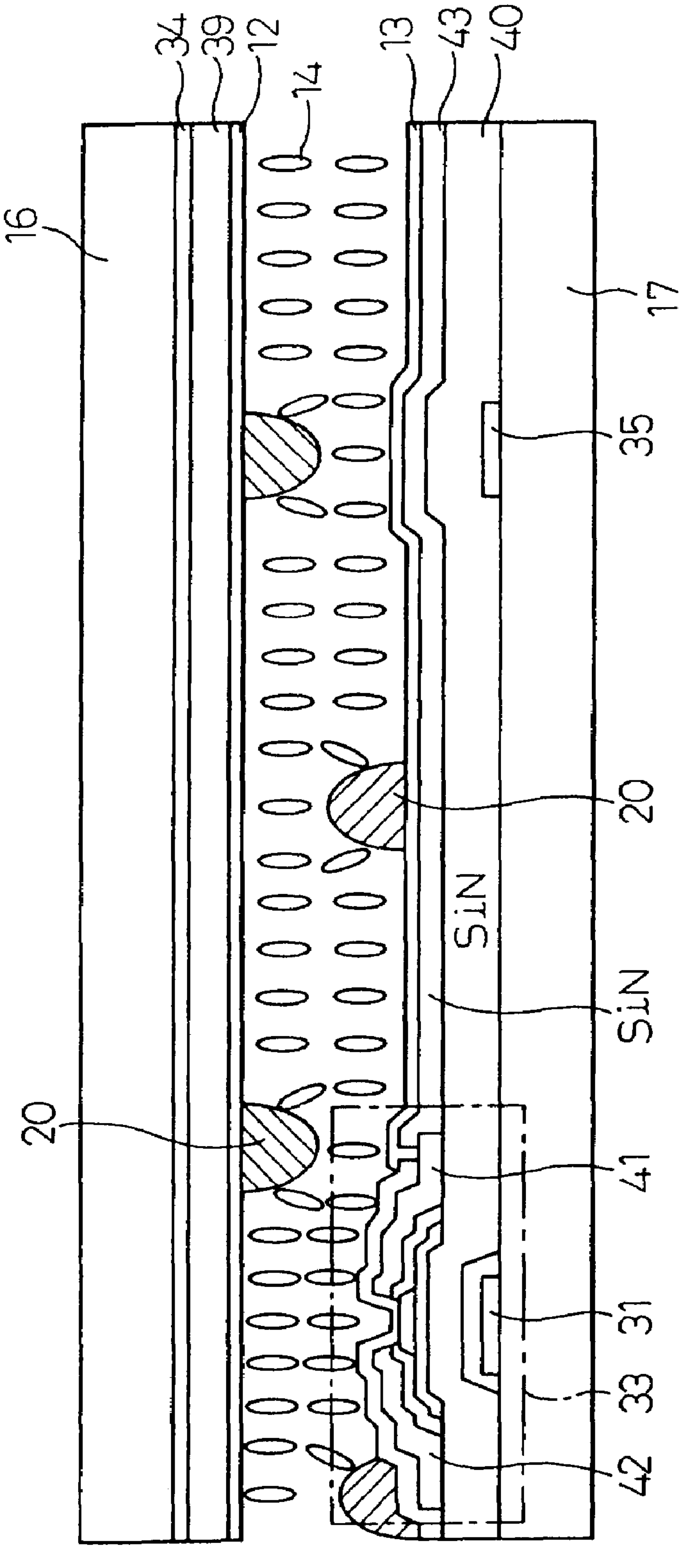


Fig.18A

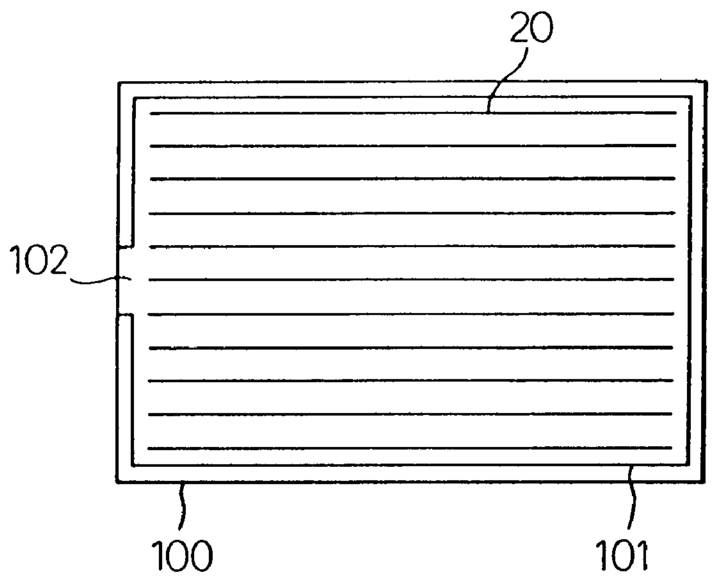


Fig.18B

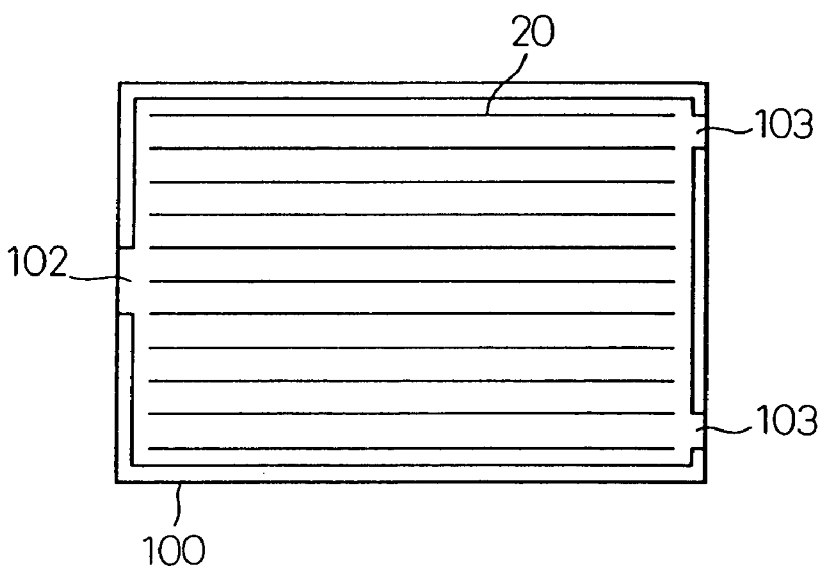


Fig.19

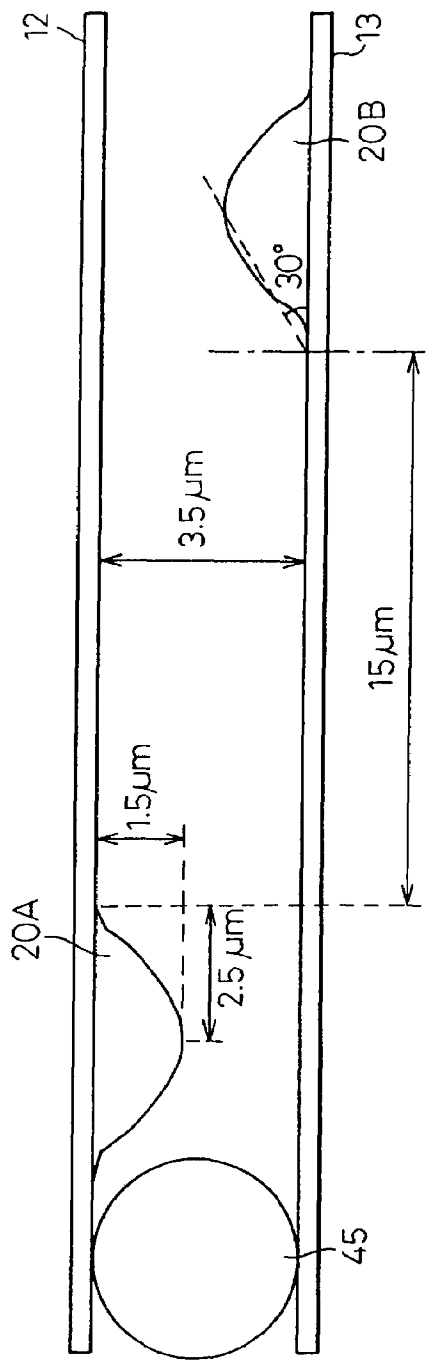


Fig.20A

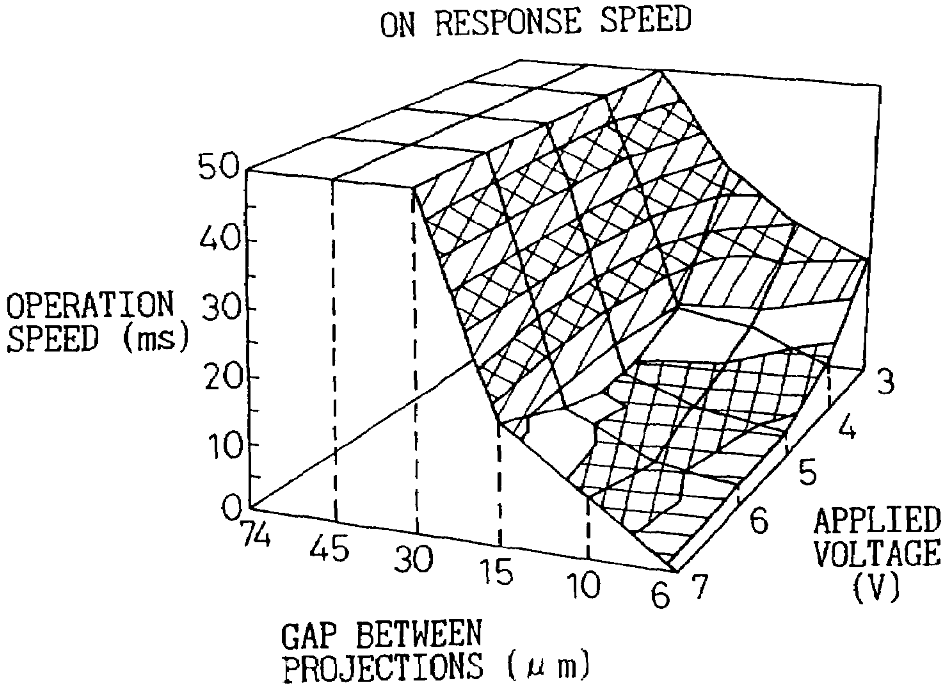


Fig.20B

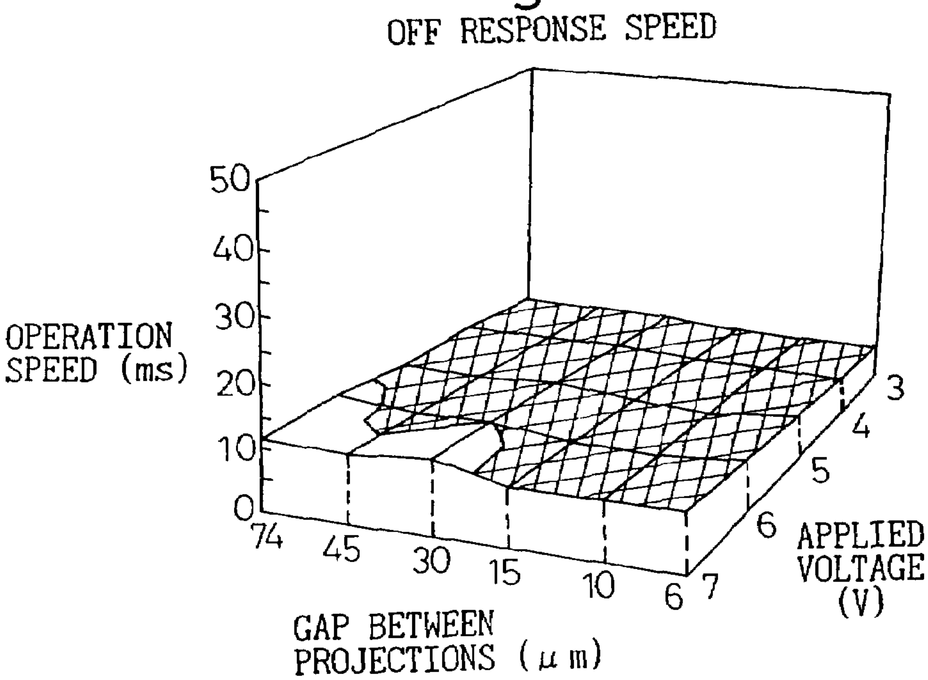


Fig.21

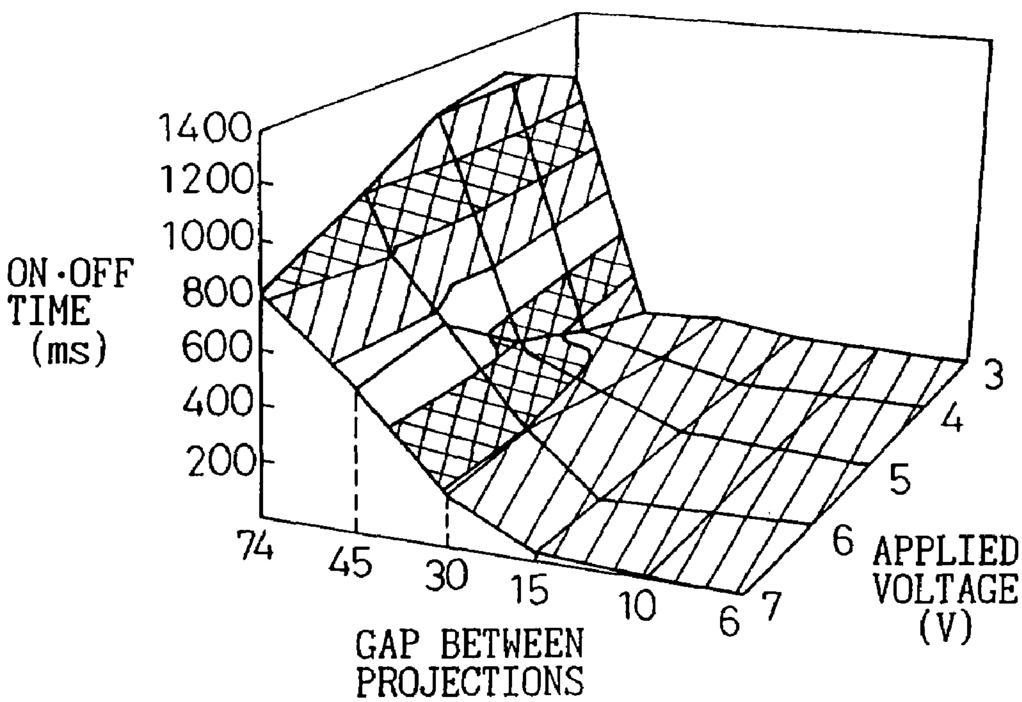

1400
1200
1000
800
600
400
200
ON·OFF
TIME
(ms)
74
45
30
15
10
6
GAP BETWEEN
PROJECTIONS
7
6
5
4
3
APPLIED
VOLTAGE
(V)

Fig. 22

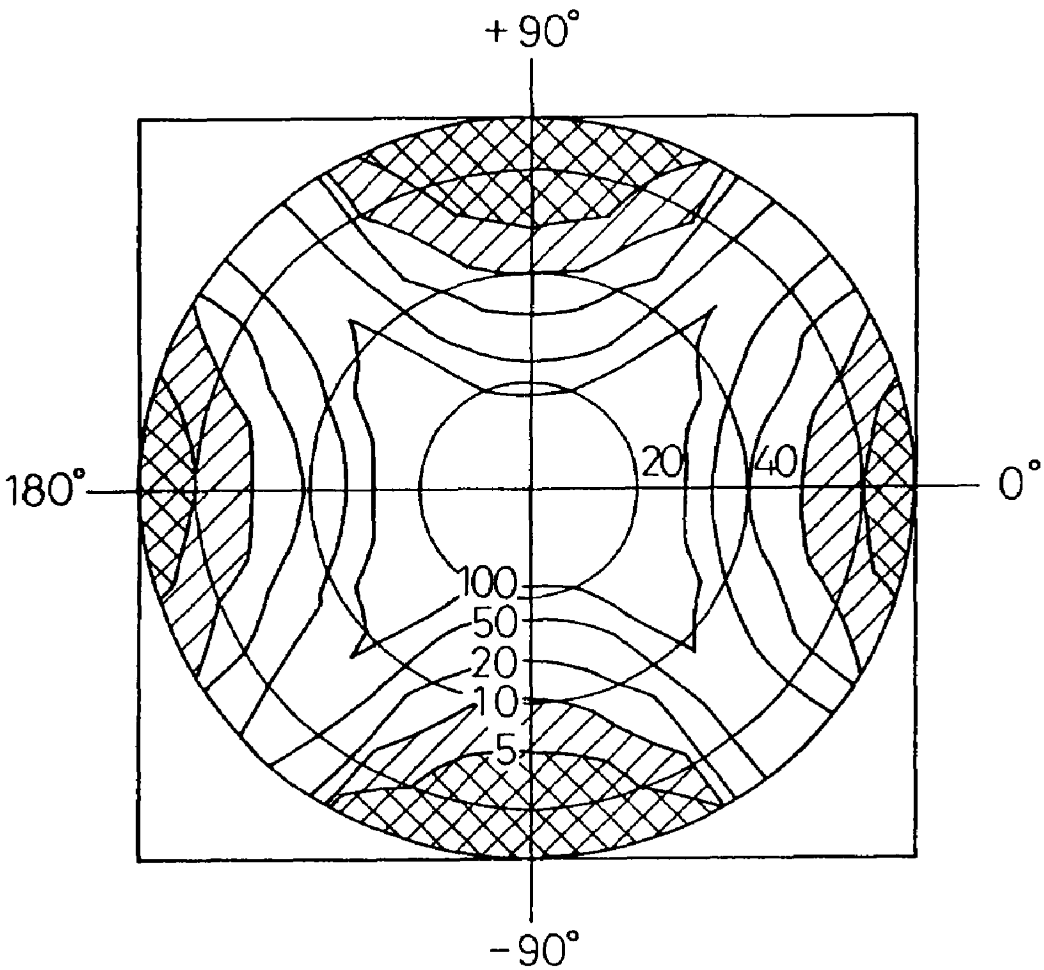


Fig.23A

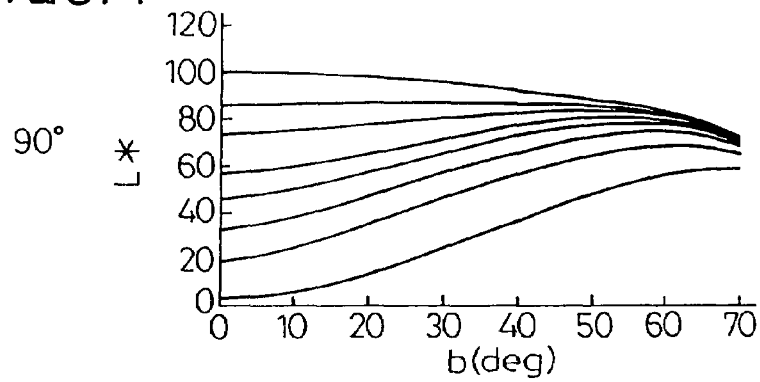


Fig.23B

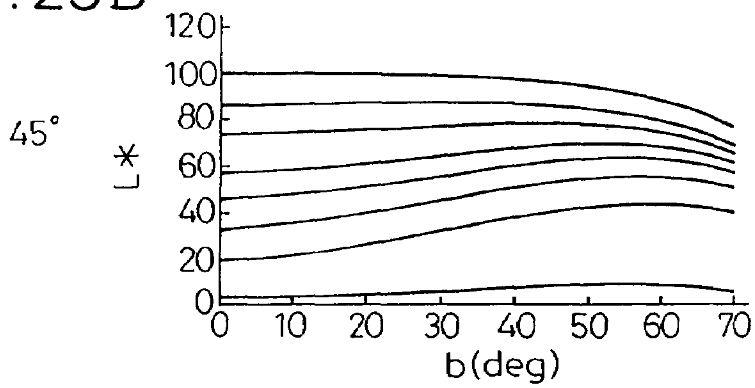


Fig.23C

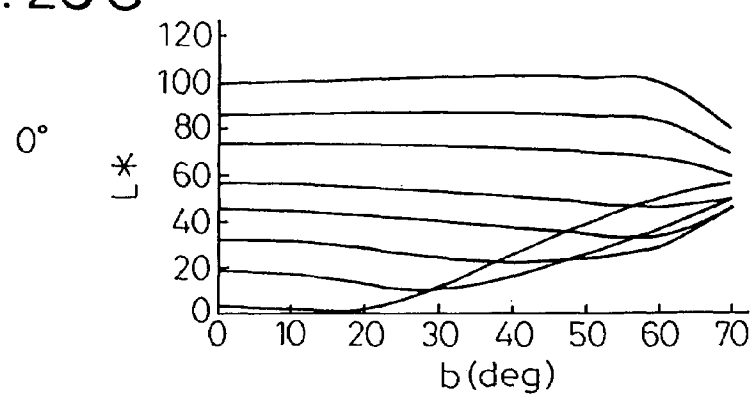


Fig.24A

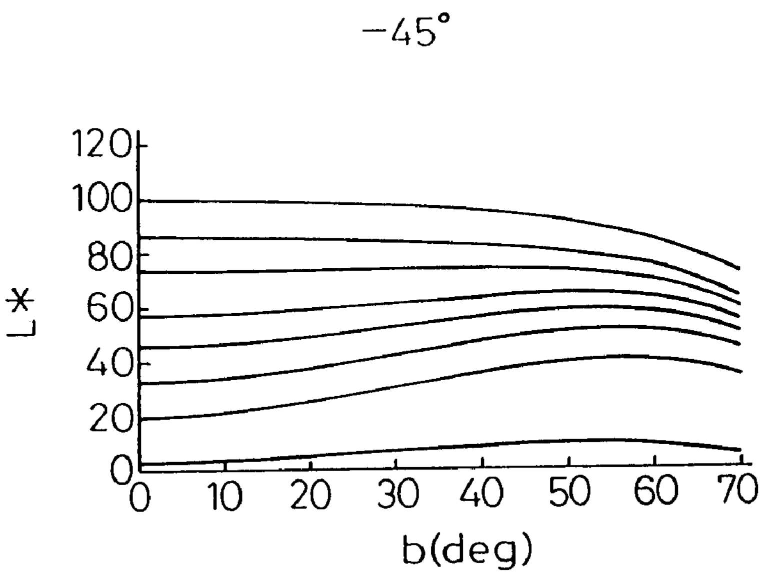


Fig.24B

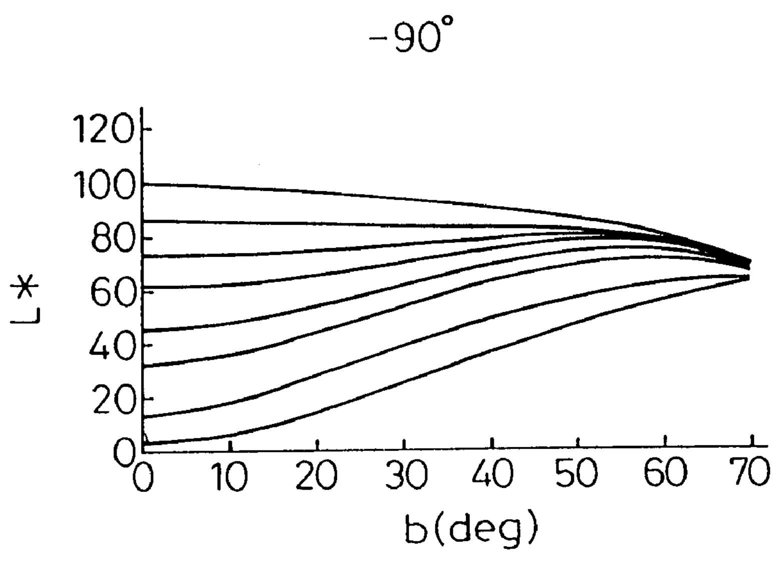


Fig.25

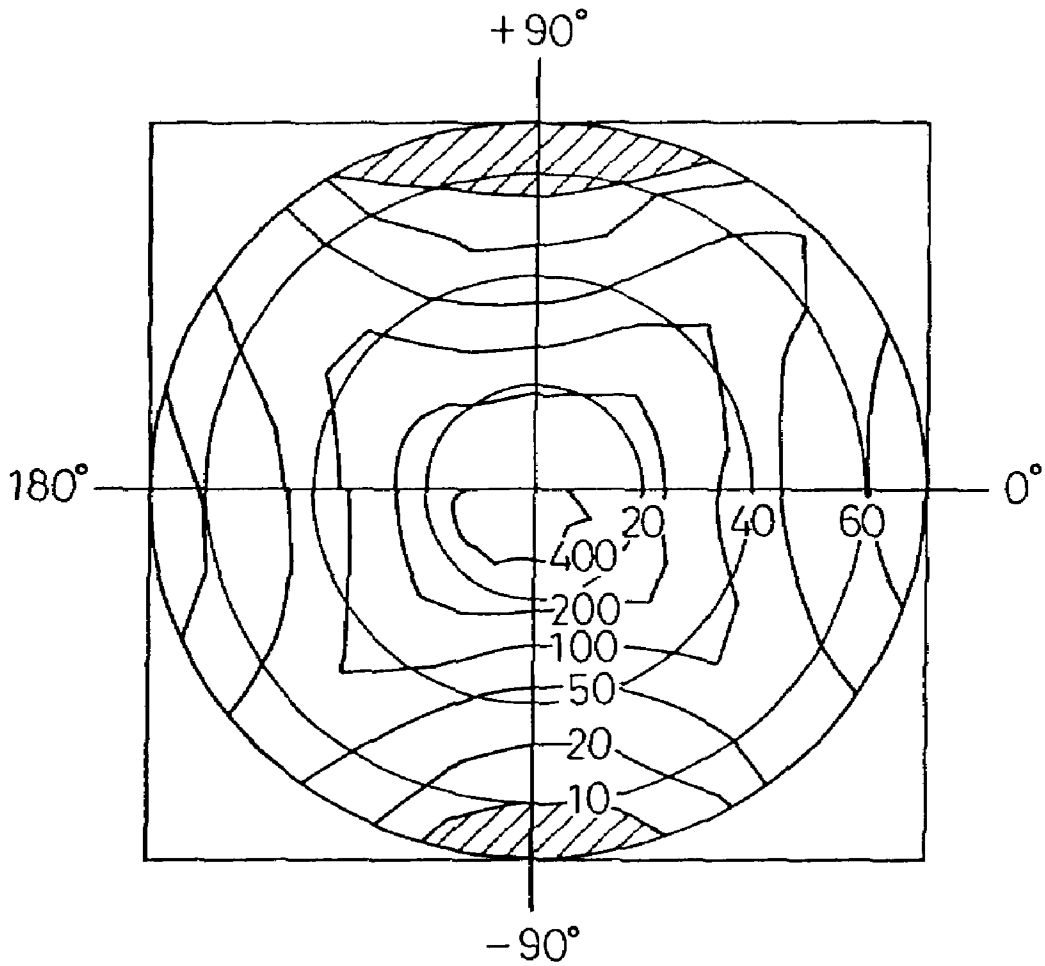


Fig.26A

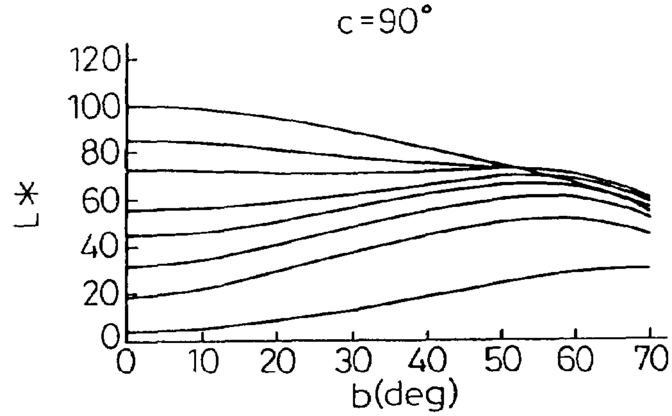


Fig.26B

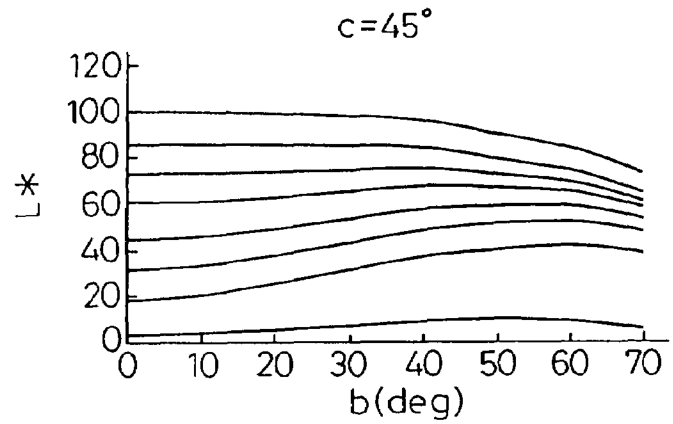


Fig.26C

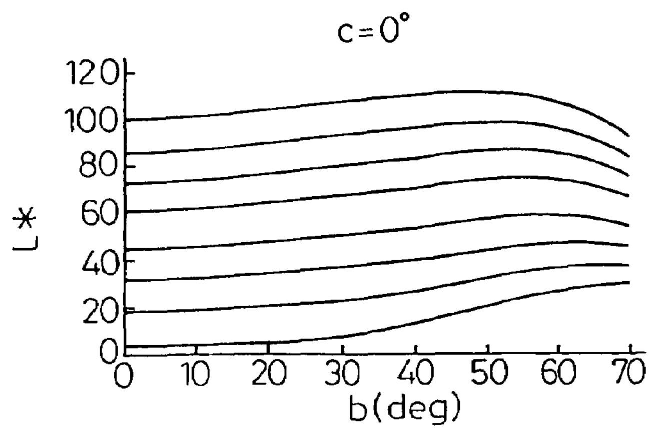


Fig. 27

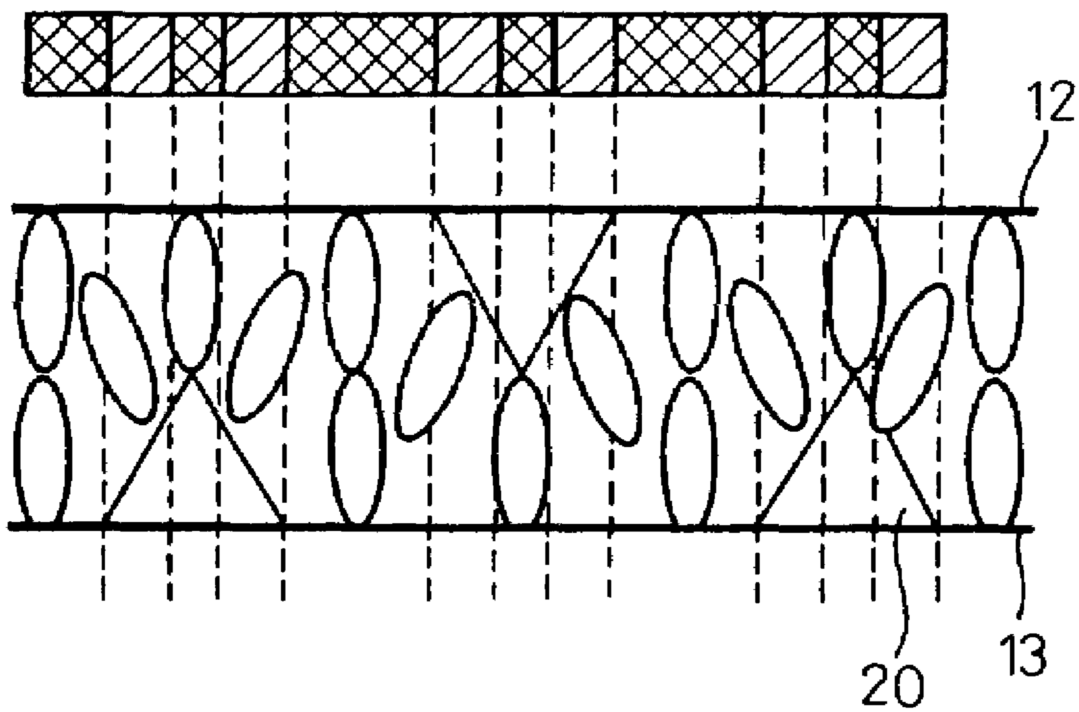


Fig.28

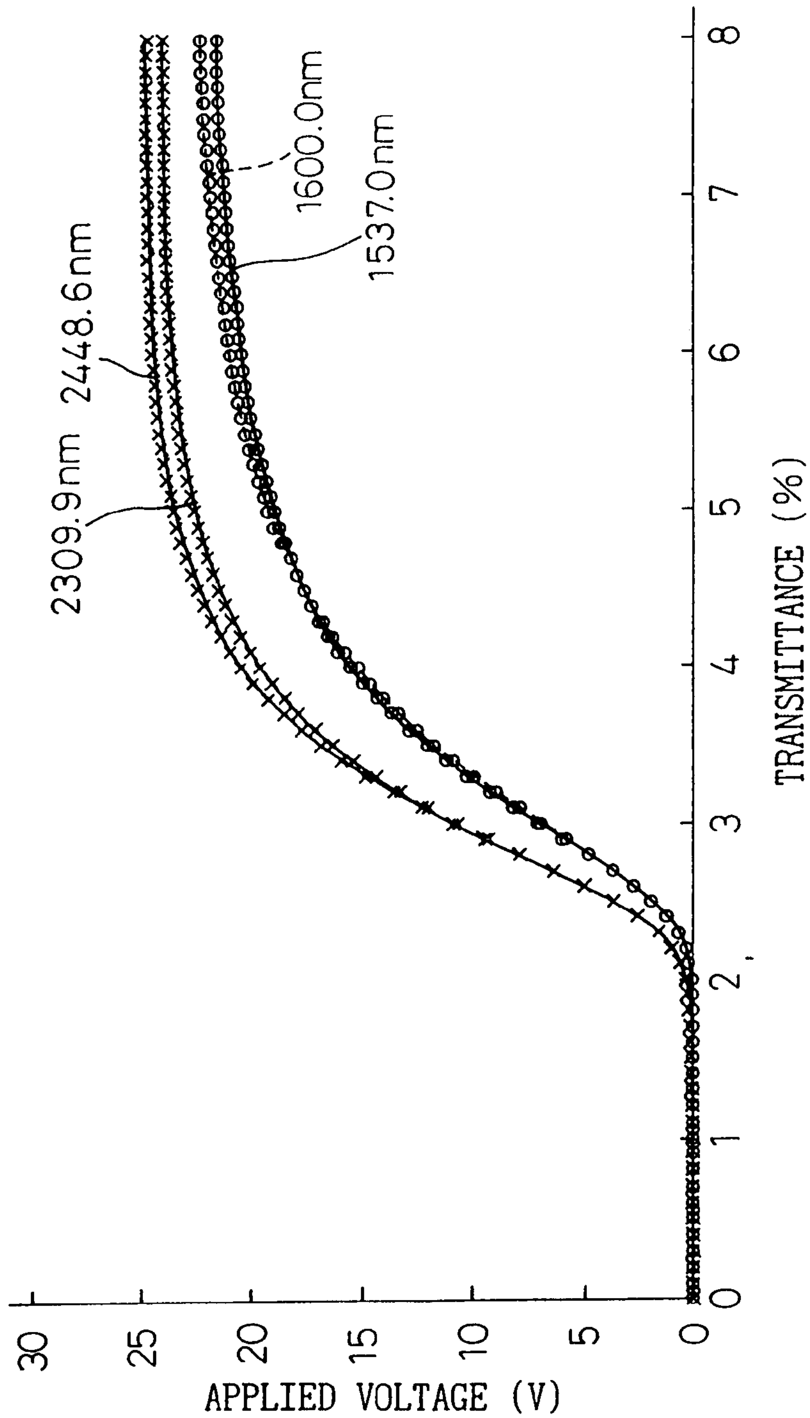

2309.9nm
2448.6nm
1600.0nm
1537.0nm
TRANSMITTANCE (%)
APPLIED VOLTAGE (V)
0
5
10
15
20
25
30
0
1
2
3
4
5
6
7
8

Fig. 29

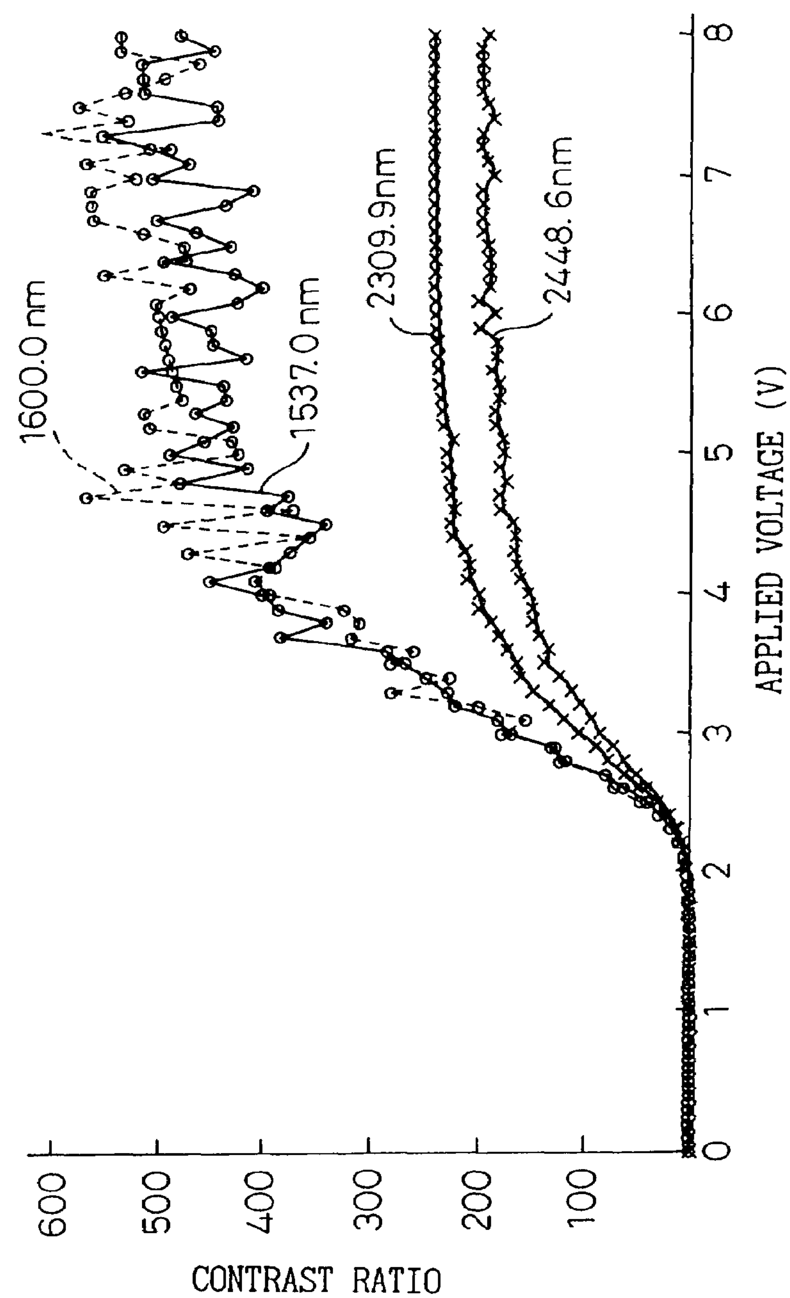

1600.0 nm
1537.0 nm
2309.9nm
2448.6nm
CONTRAST RATIO
600
500
400
300
200
100
0
1
2
3
4
5
6
7
8
APPLIED VOLTAGE (V)

Fig.30

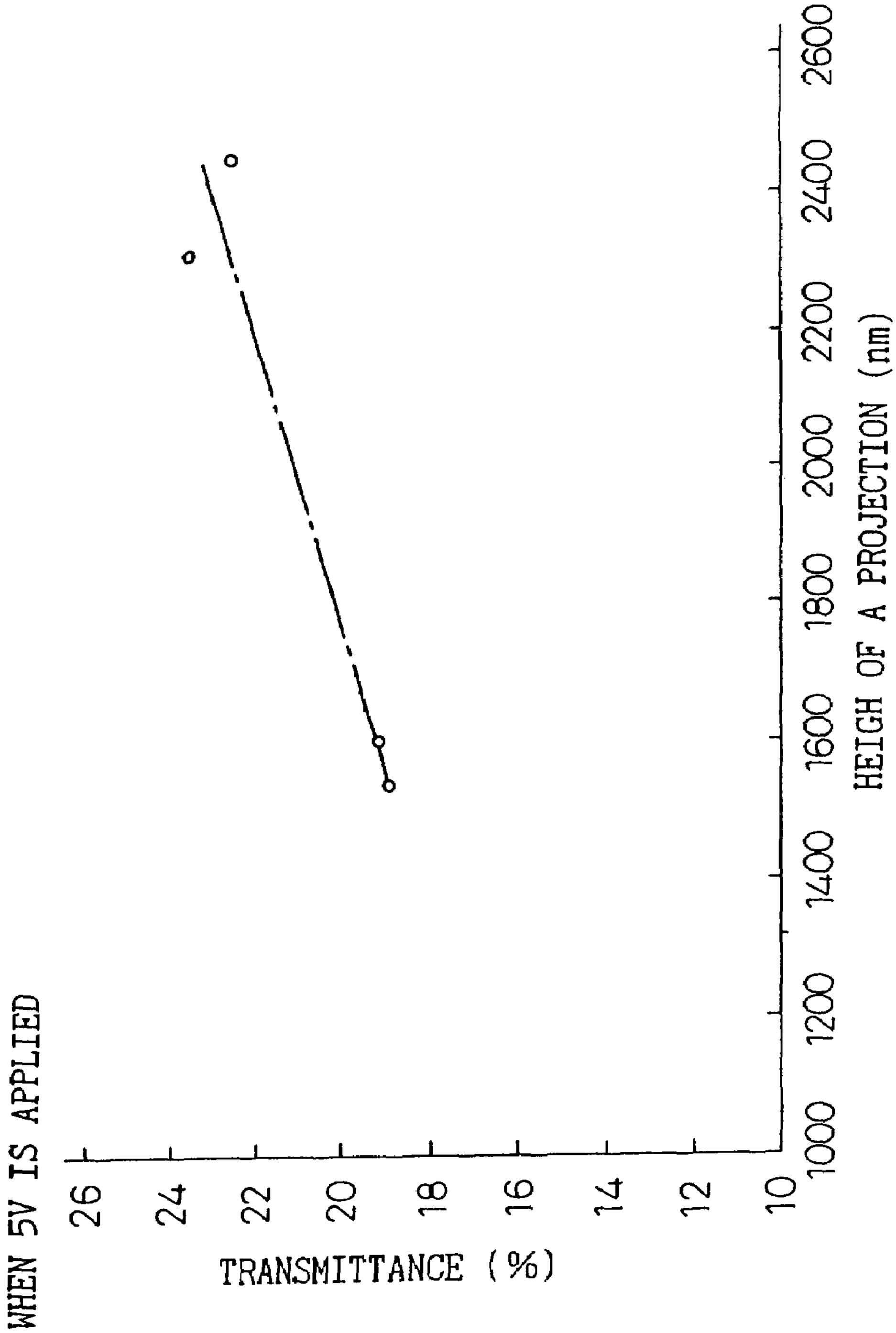

WHEN 5V IS APPLIED
TRANSMITTANCE (%)
26
24
22
20
18
16
14
12
10
1000
1200
1400
1600
1800
2000
2200
2400
2600
HEIGH OF A PROJECTION (nm)

Fig. 31

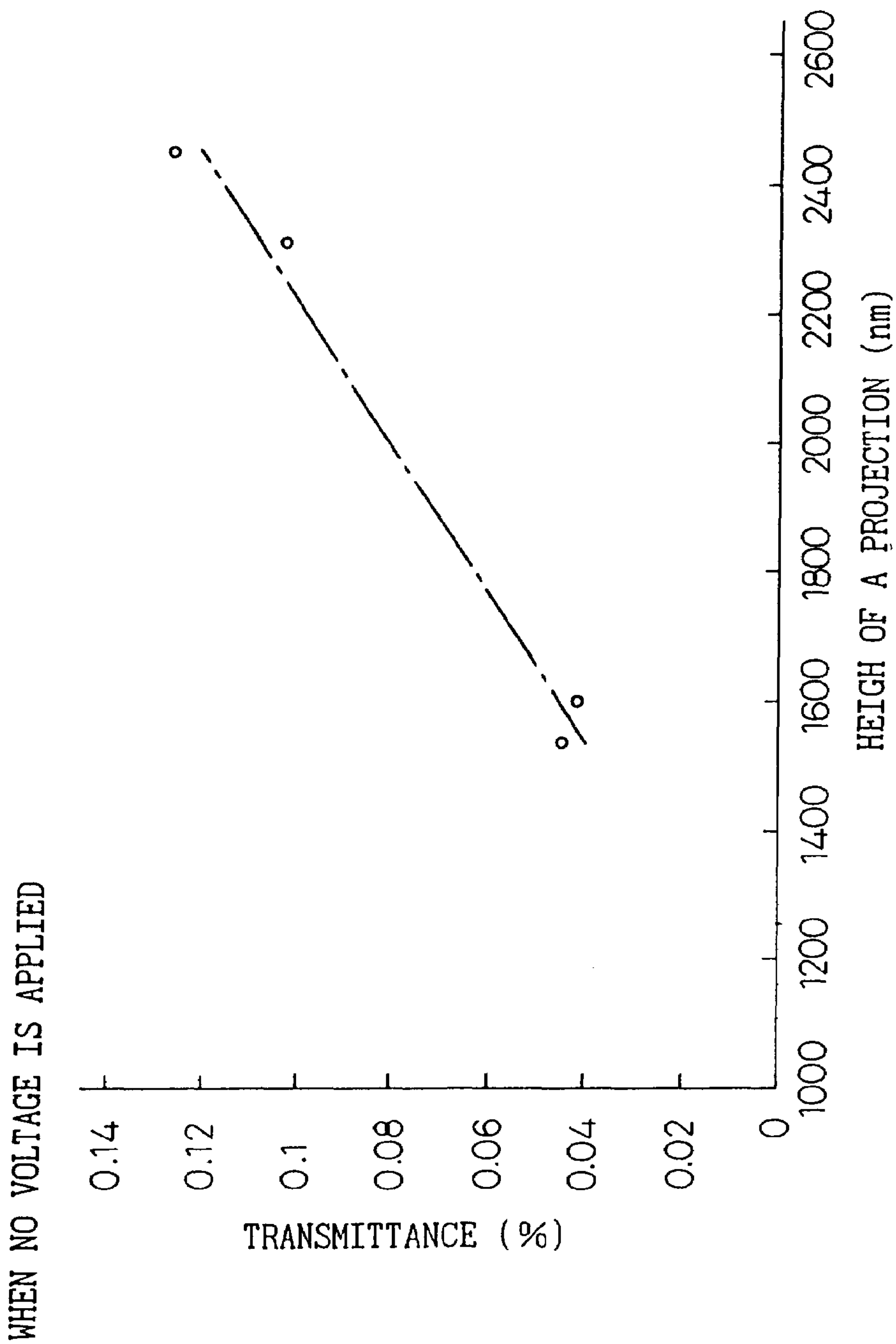

WHEN NO VOLTAGE IS APPLIED
TRANSMITTANCE (%)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1000
1200
1400
1600
1800
2000
2200
2400
2600
HEIGH OF A PROJECTION (nm)

Fig.32

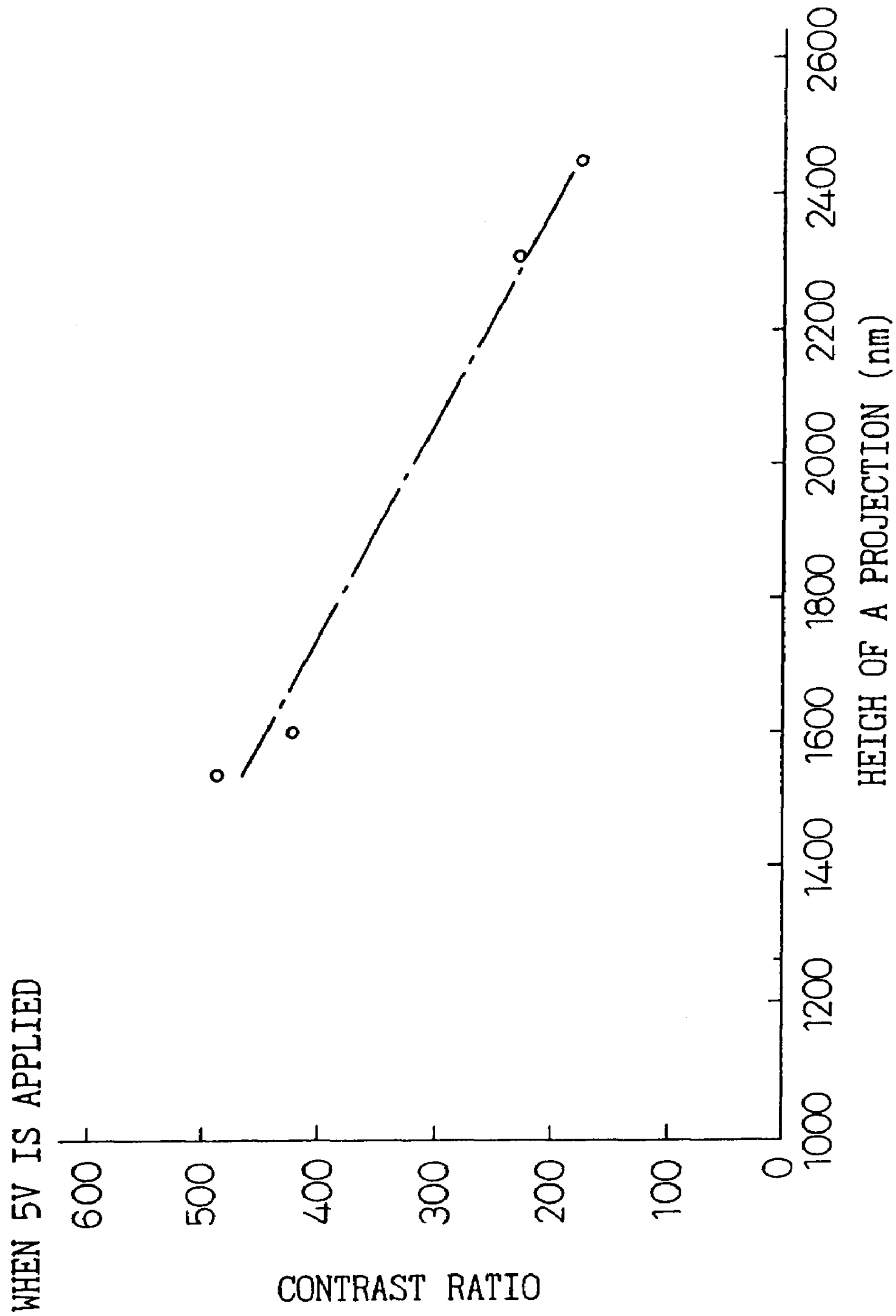

WHEN 5V IS APPLIED
CONTRAST RATIO
600
500
400
300
200
100
0
1000
1200
1400
1600
1800
2000
2200
2400
2600
HEIGH OF A PROJECTION (nm)

Fig.33

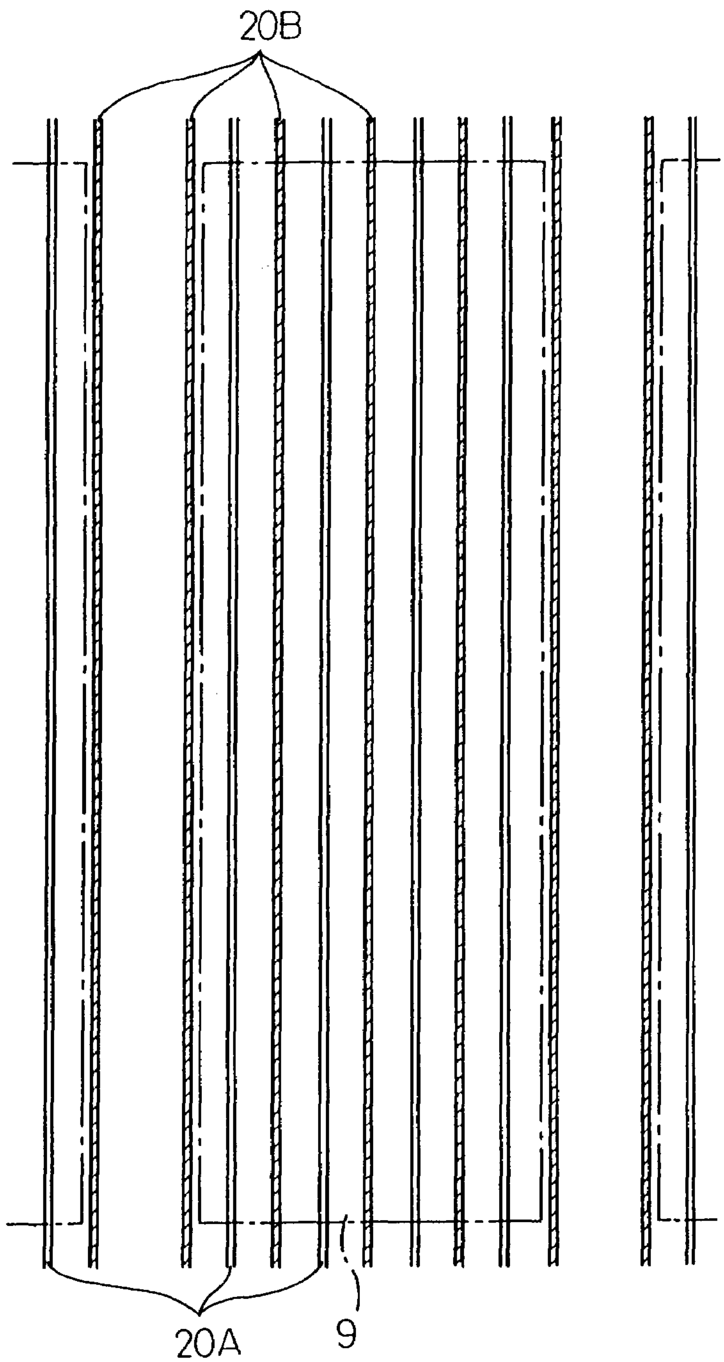


Fig.34

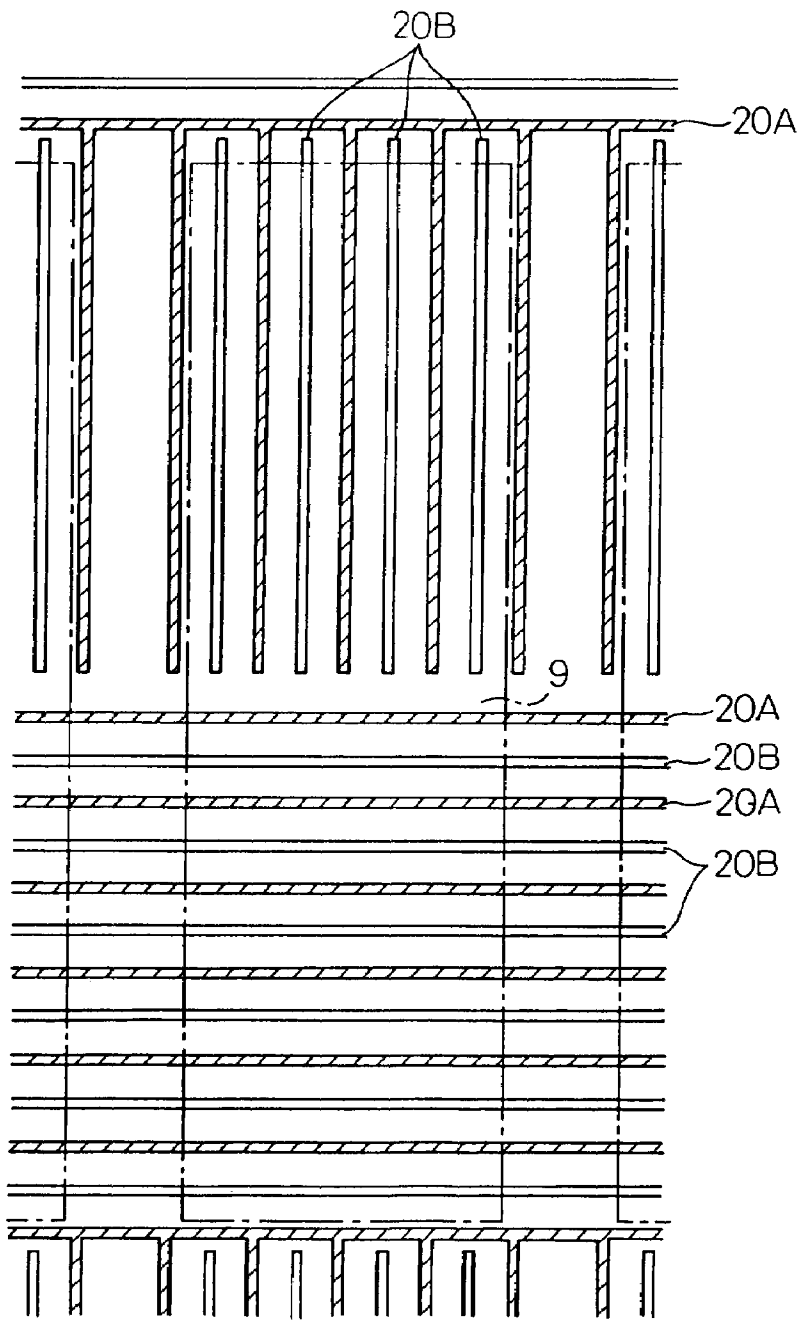


Fig.35

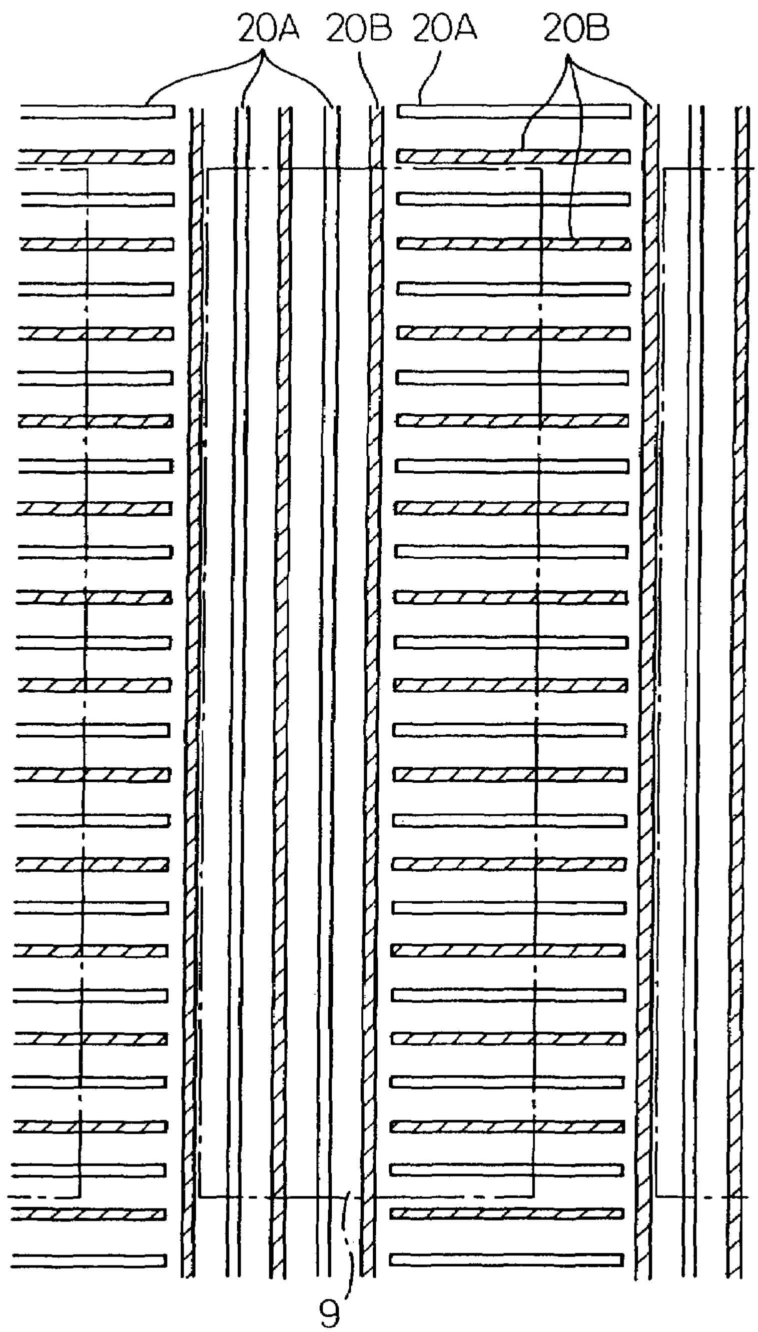


Fig.36

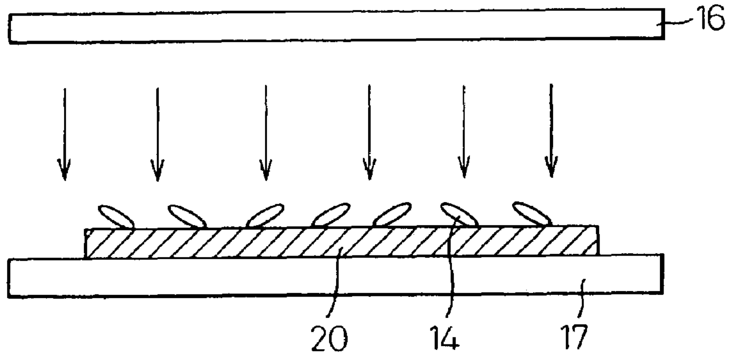


Fig.37A

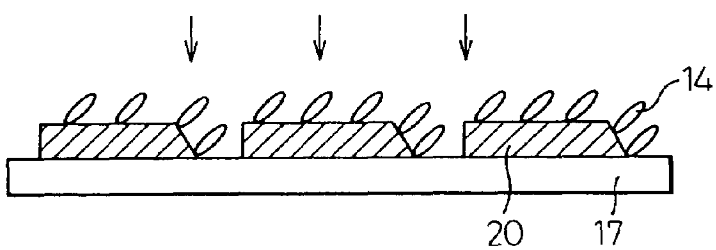


Fig.37B

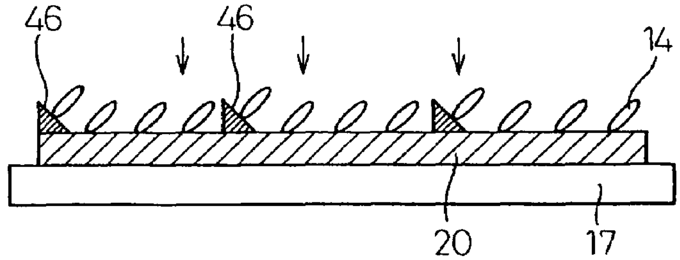


Fig.38A

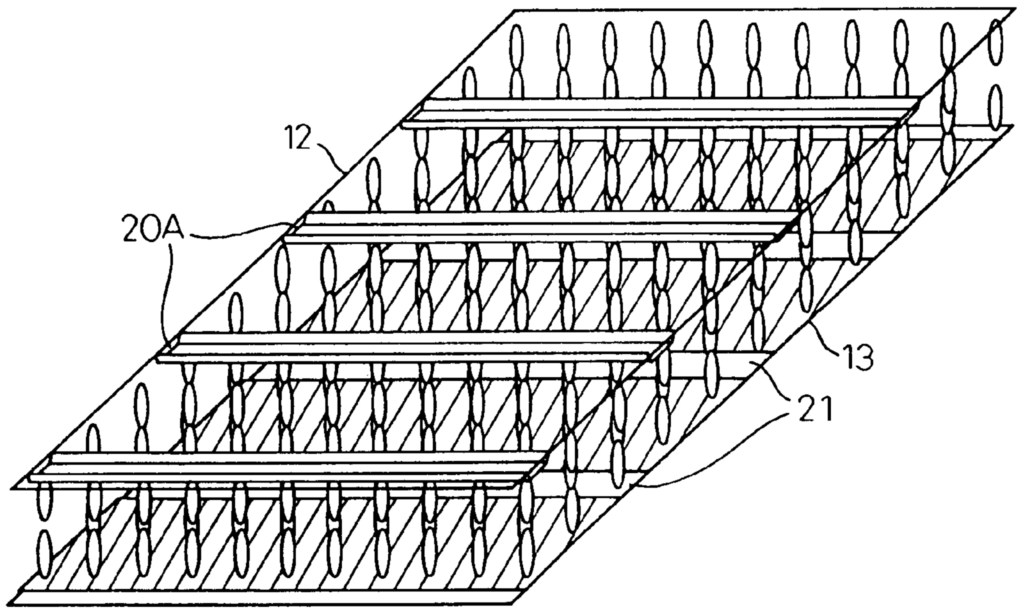


Fig.38B

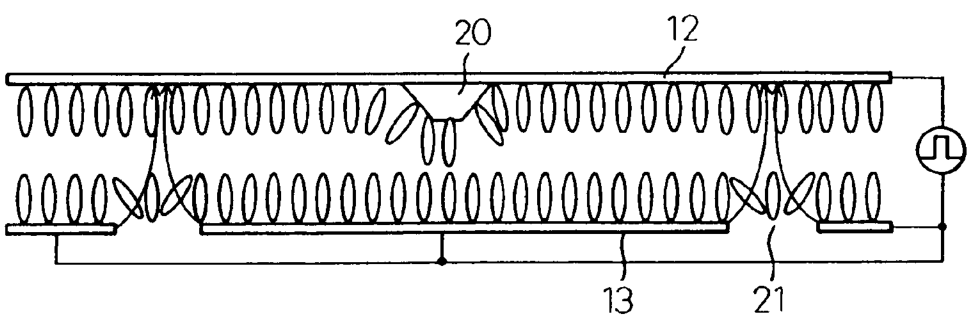


Fig.39

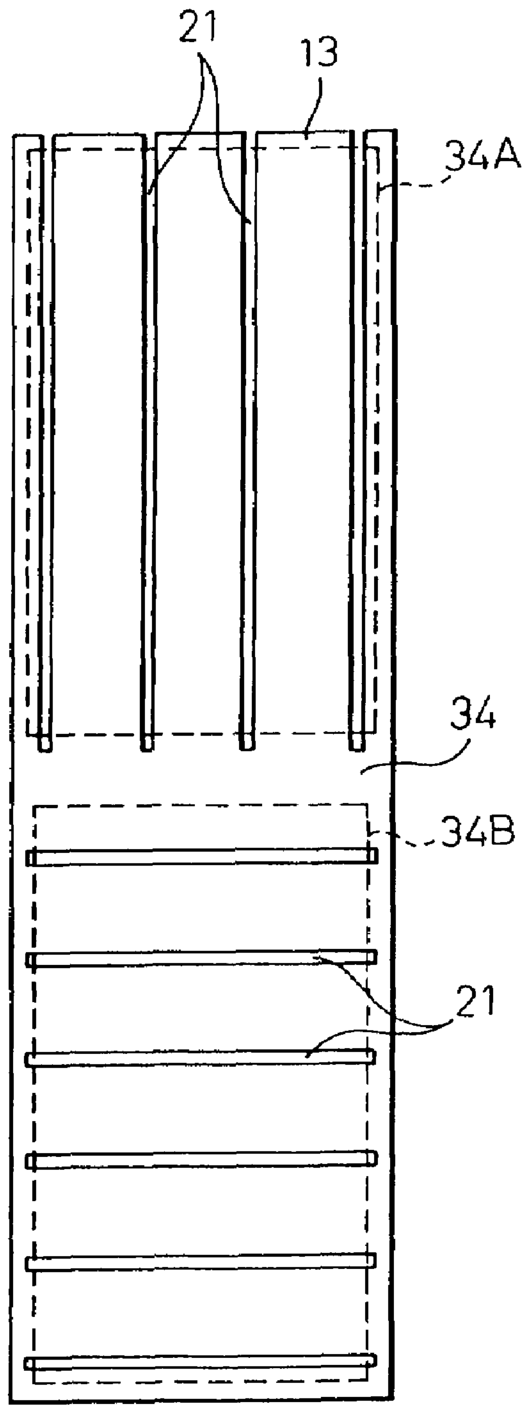


Fig.40

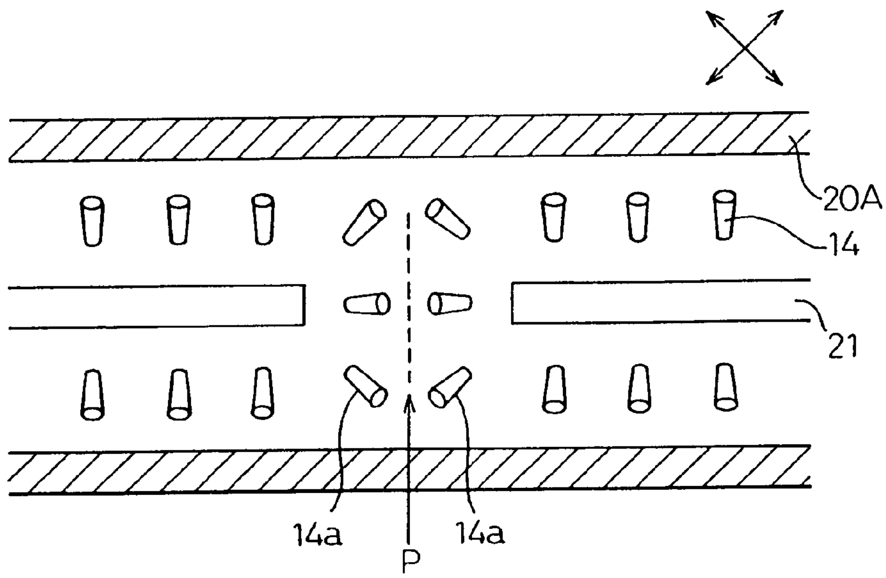


Fig.41

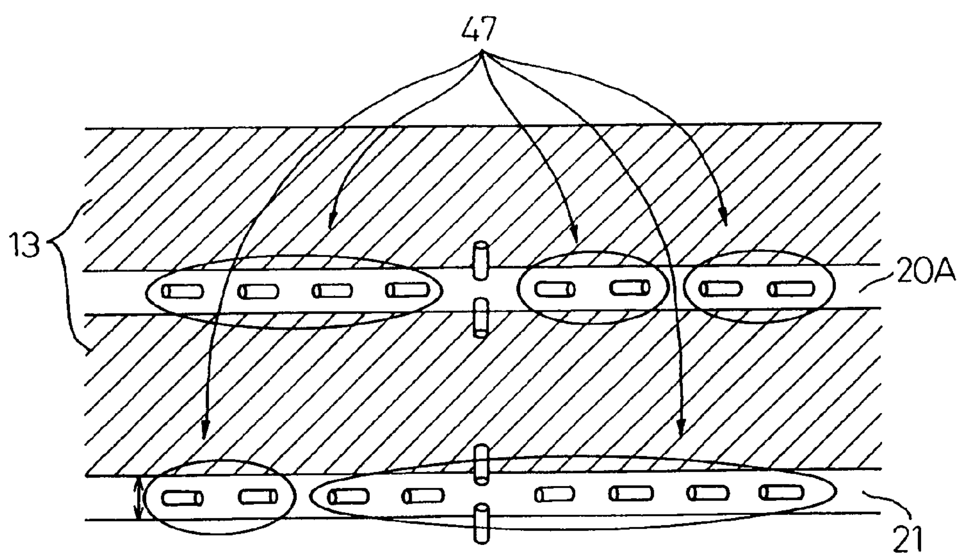


Fig. 42

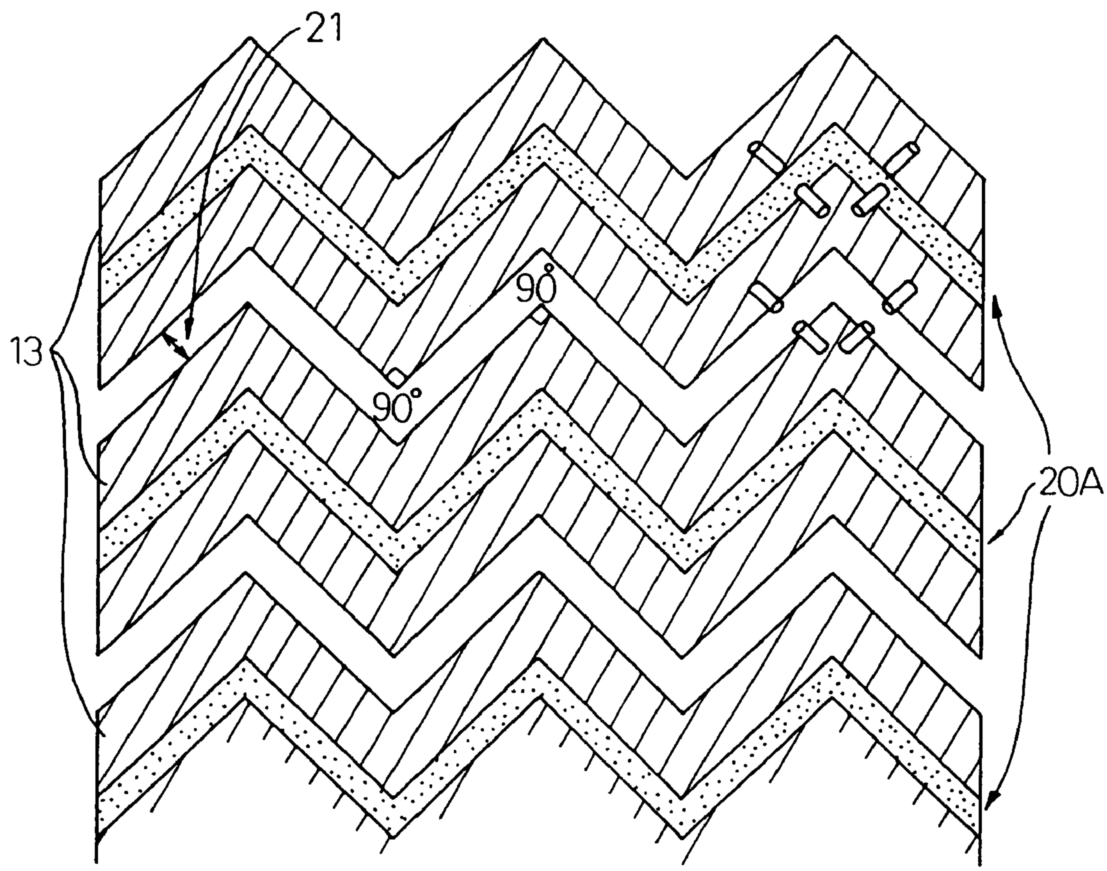


Fig. 43

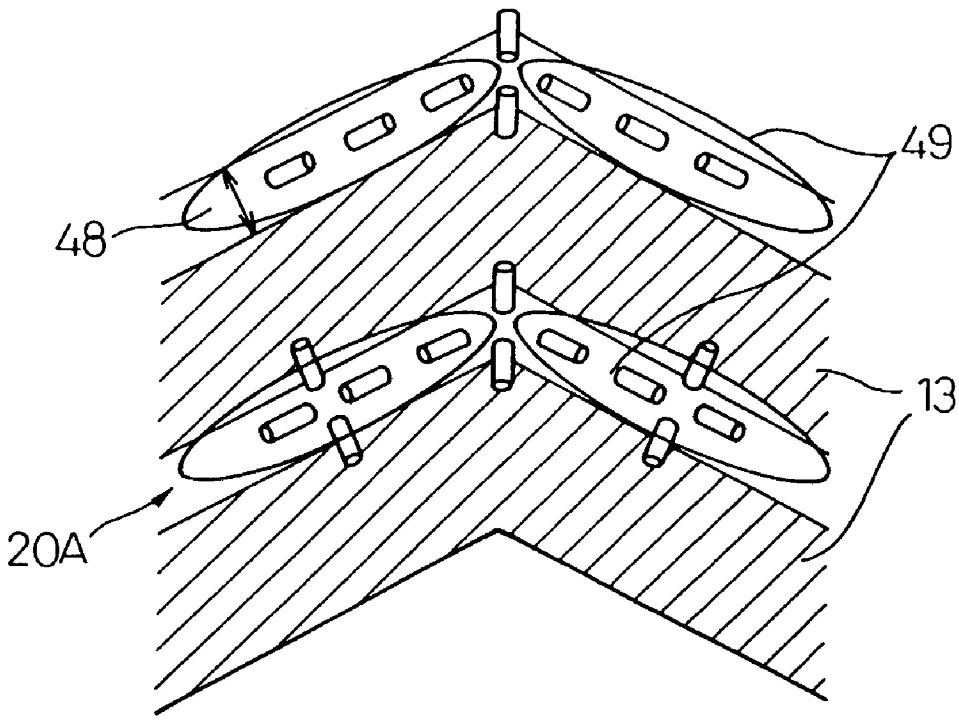


Fig. 44

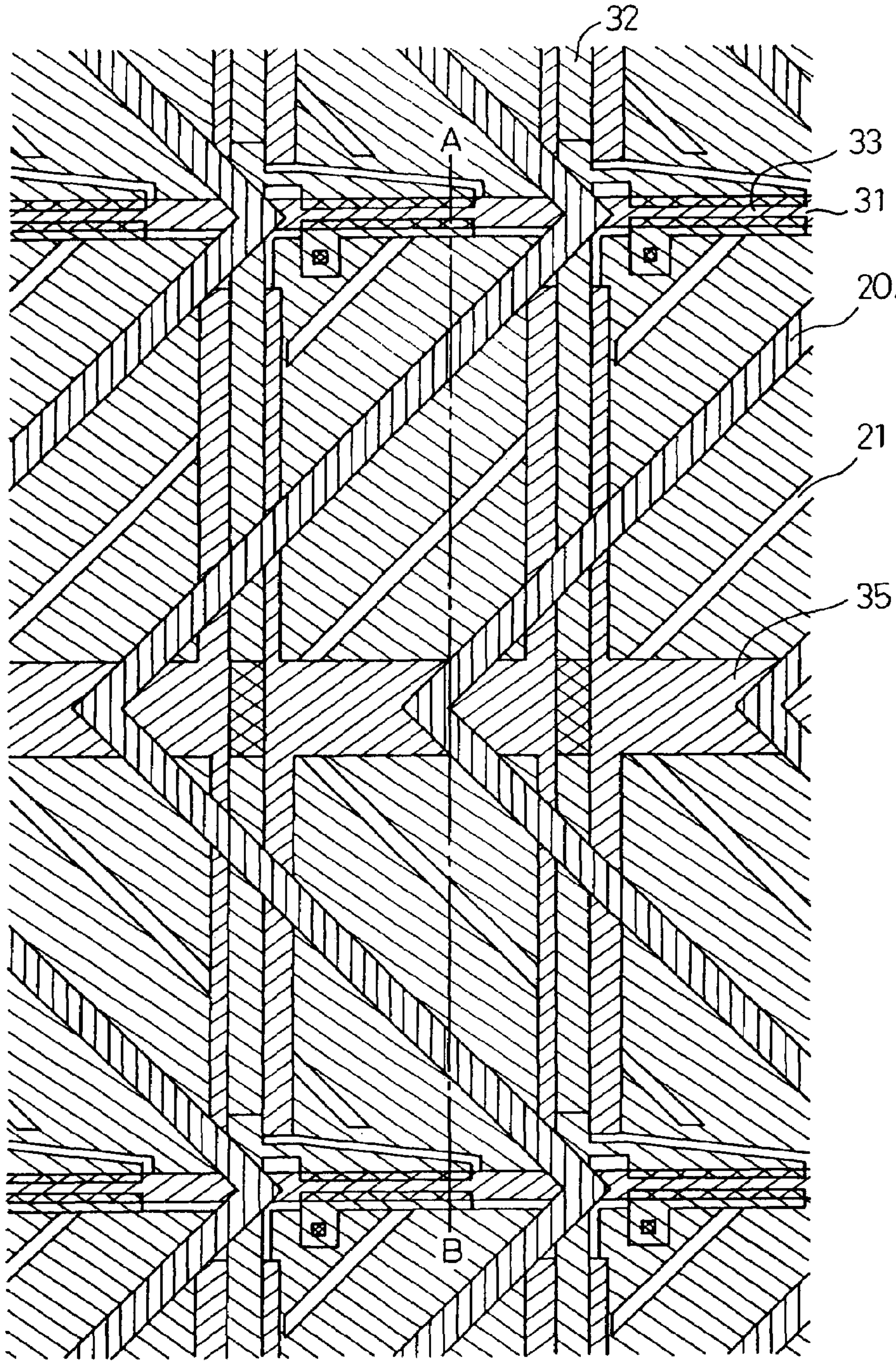


Fig.45

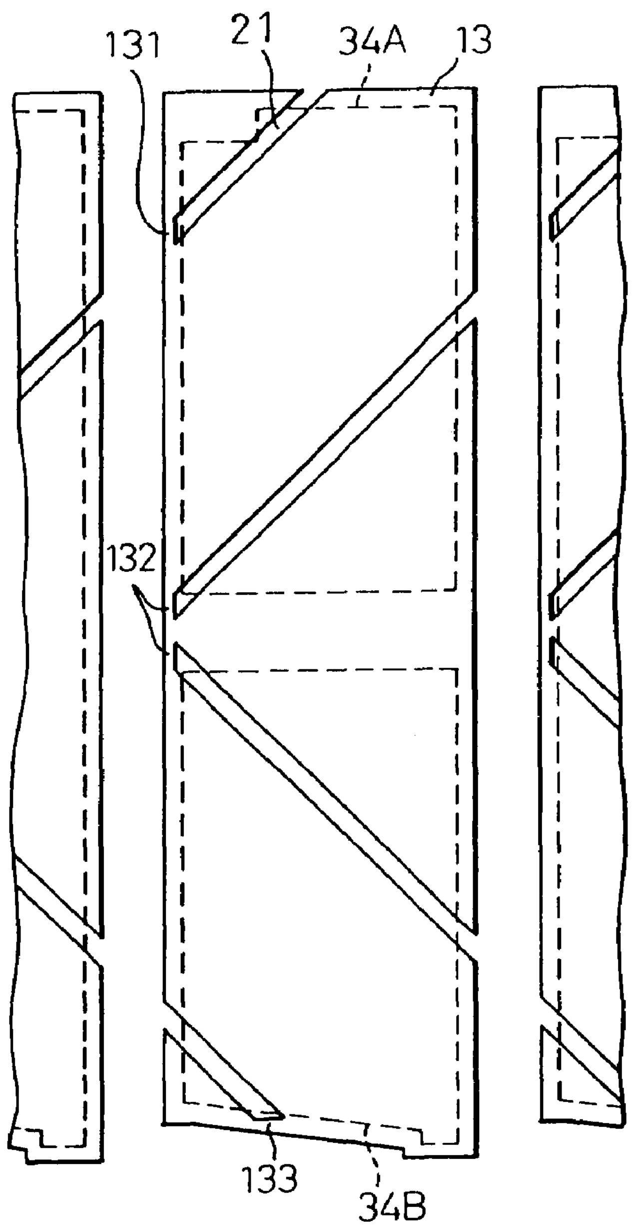


Fig.46

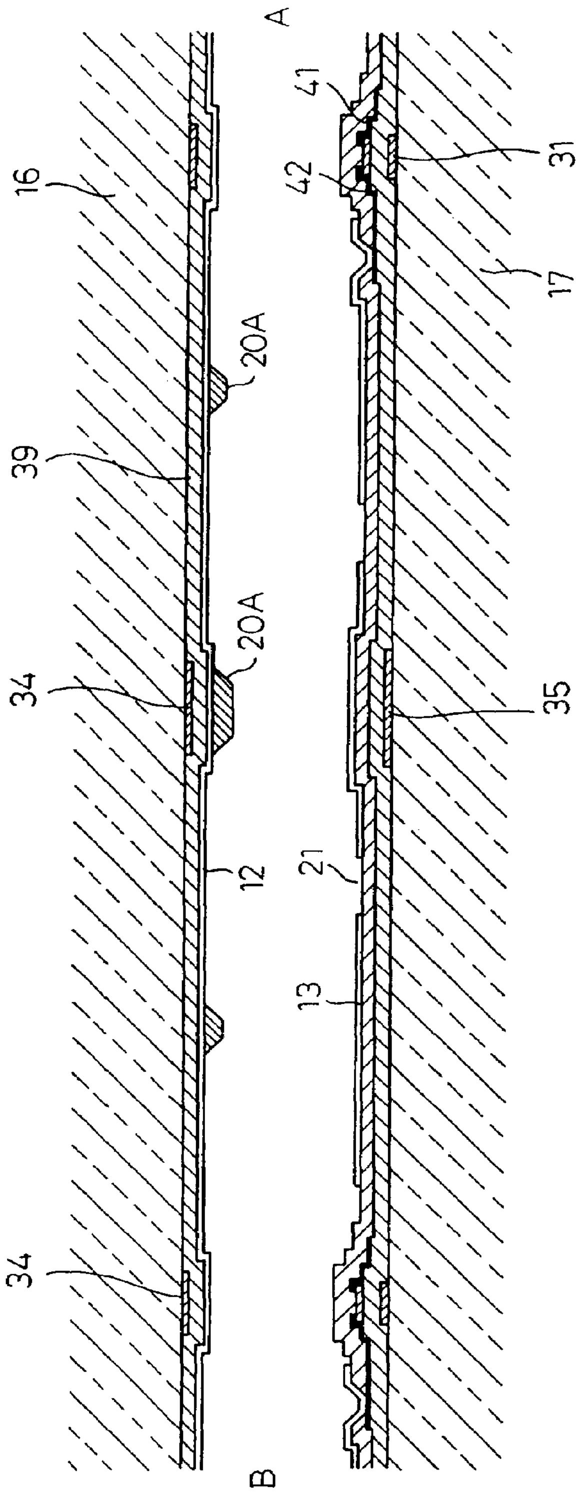


Fig. 47

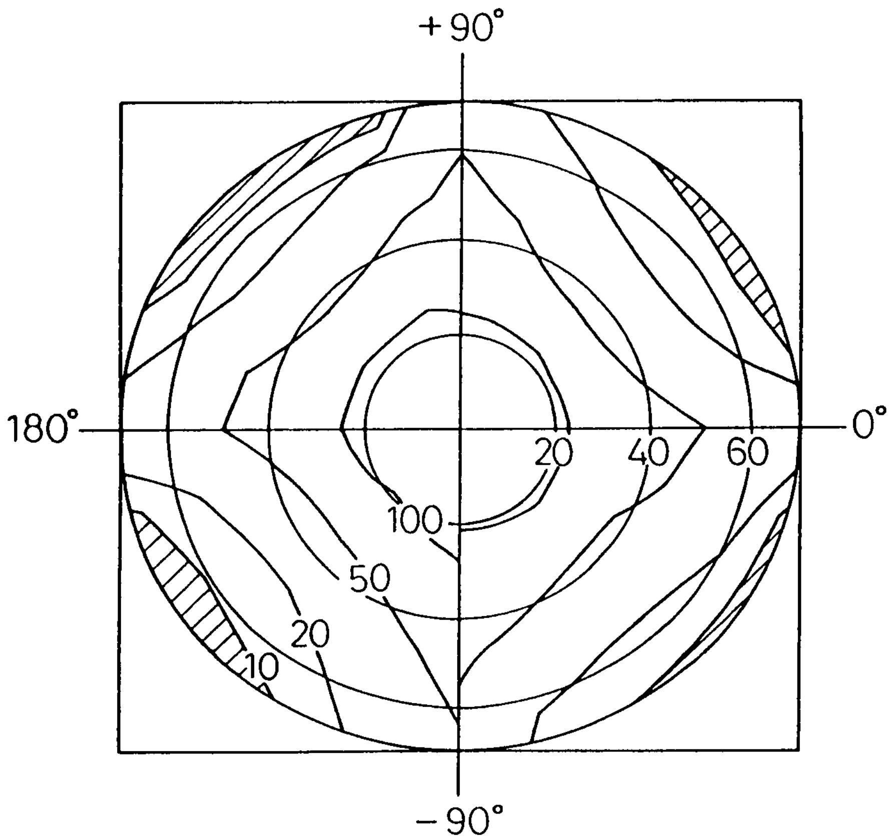


Fig.48A

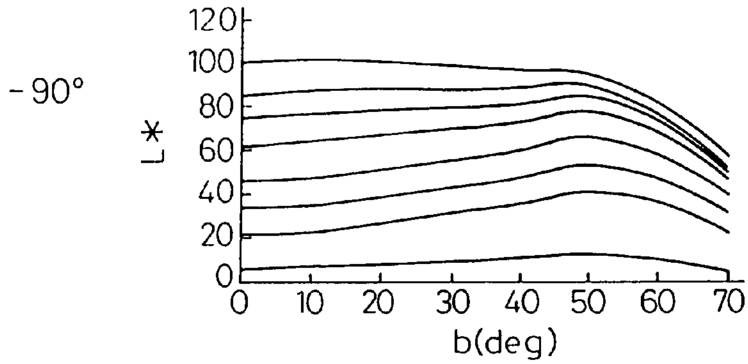


Fig.48B

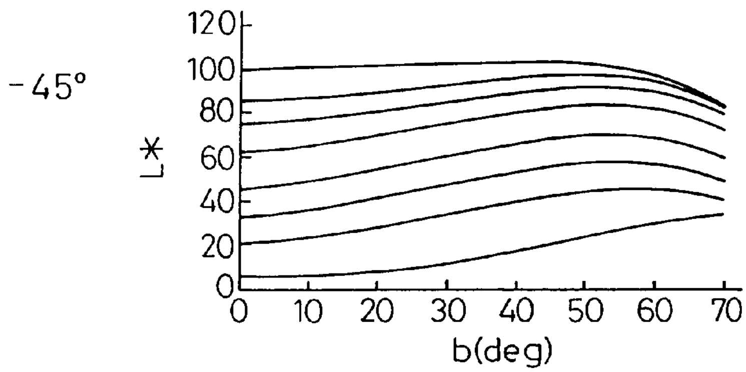


Fig.48C

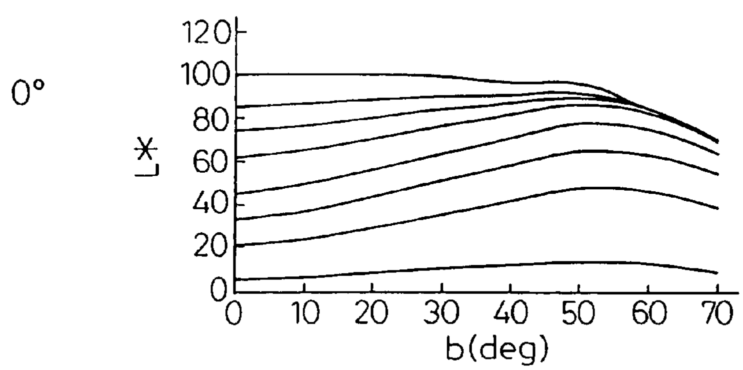


Fig.49A

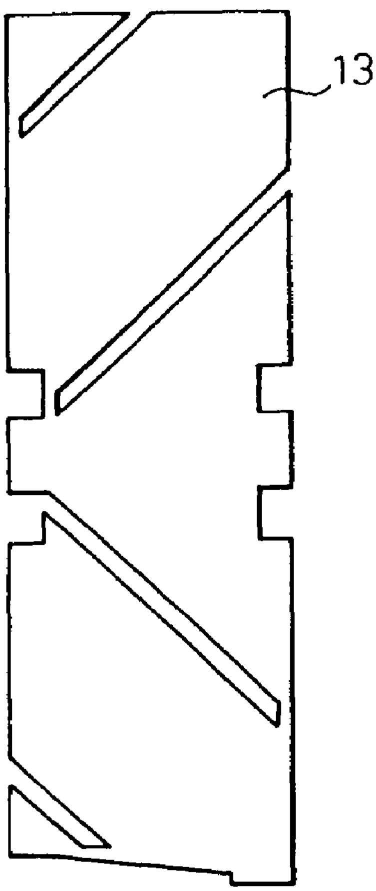


Fig.49B

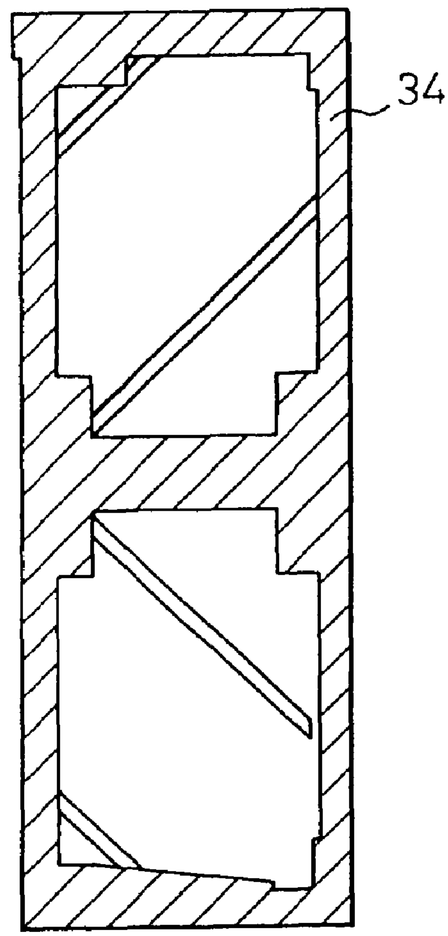


Fig.50A

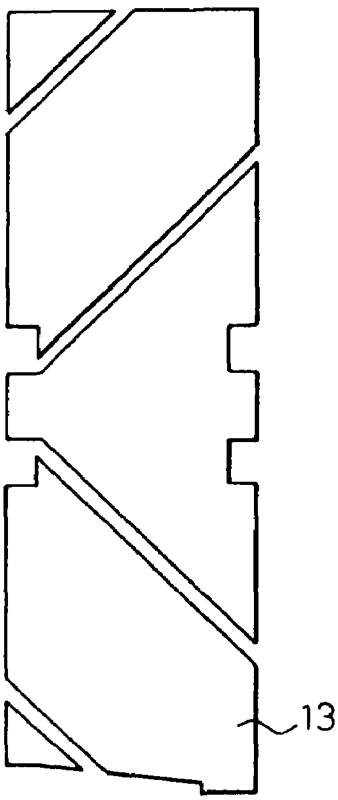


Fig.50B

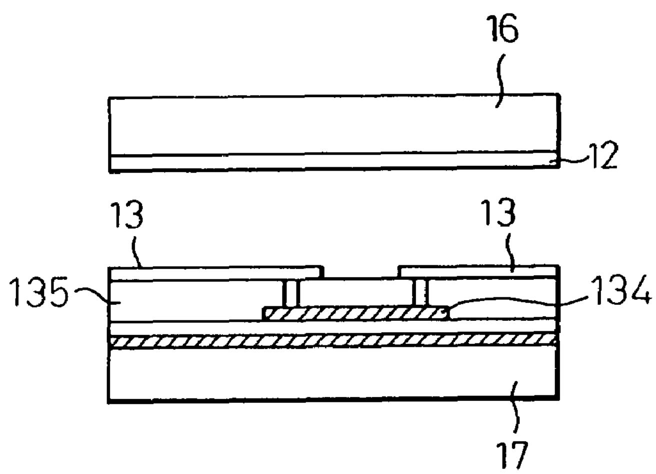


Fig.51

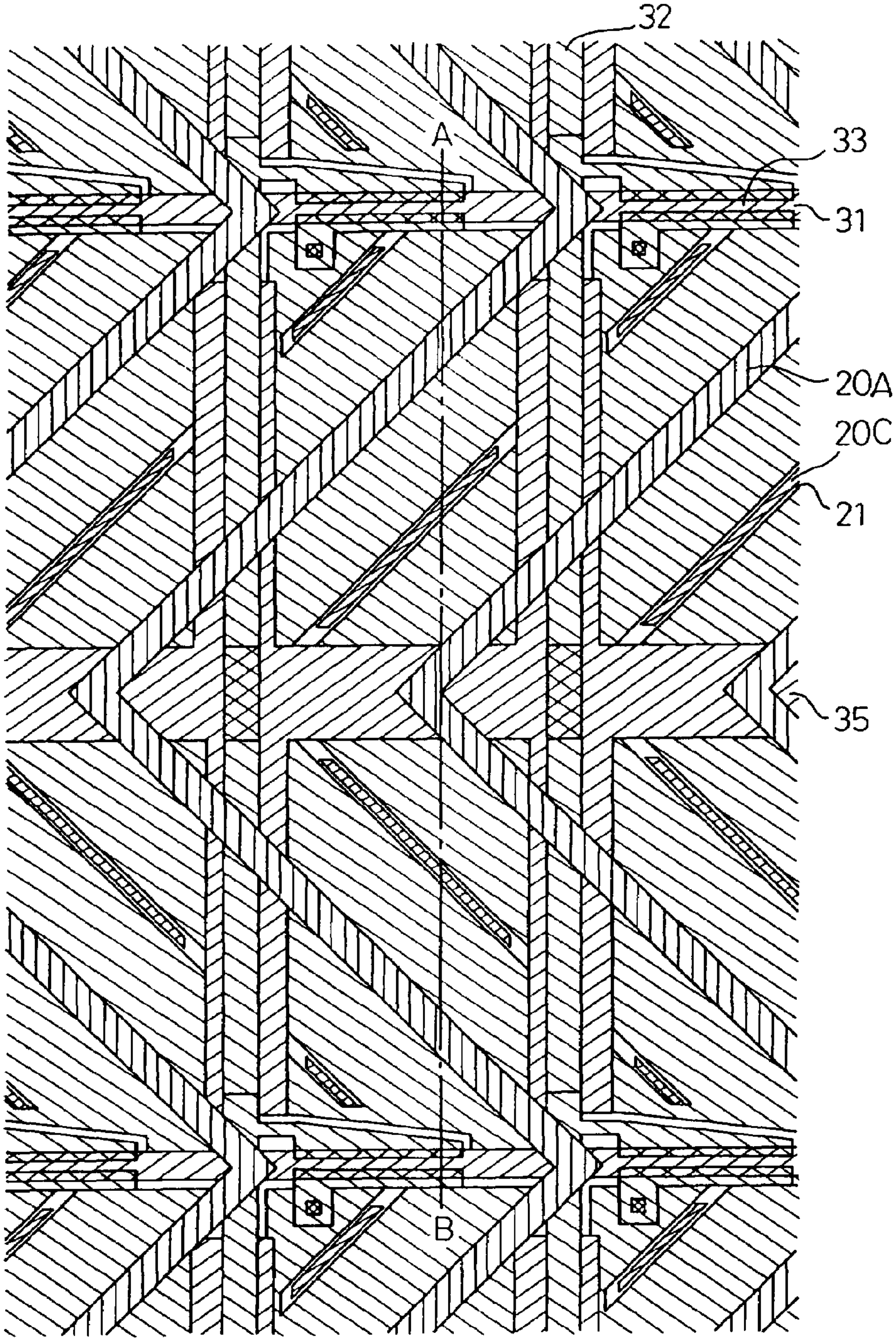


Fig.52

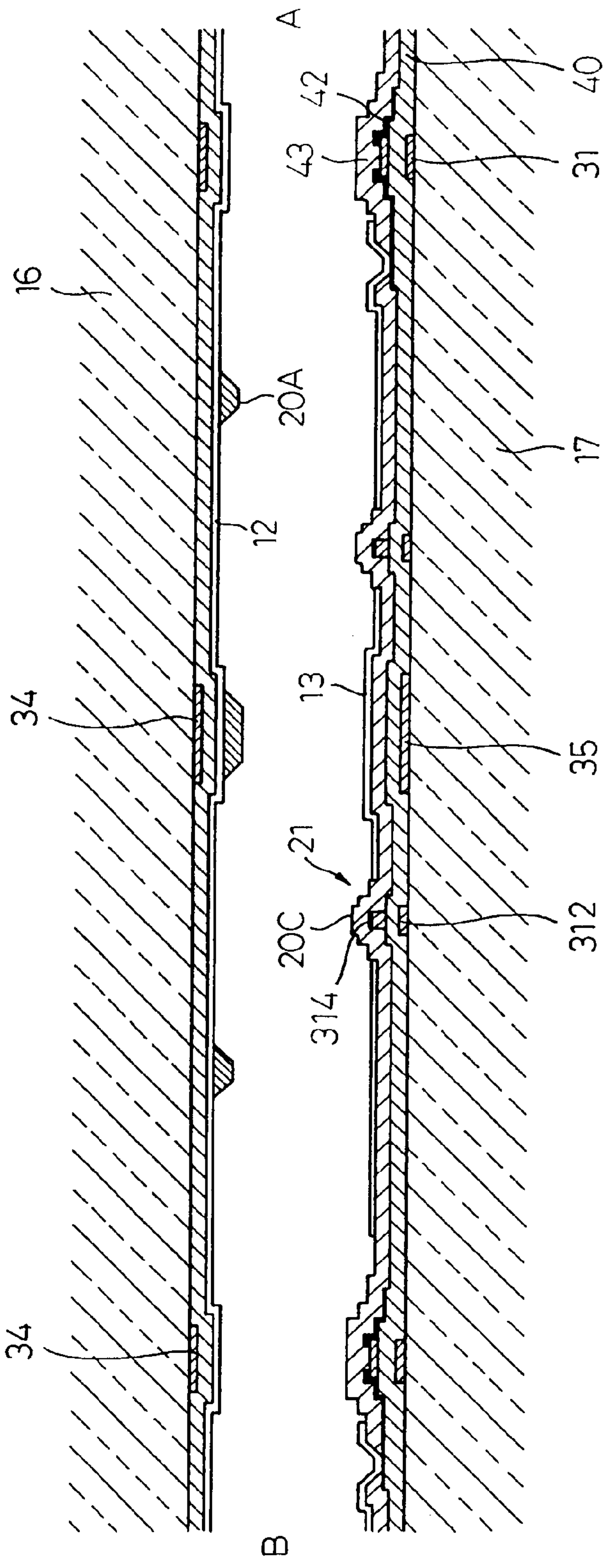


Fig.53A

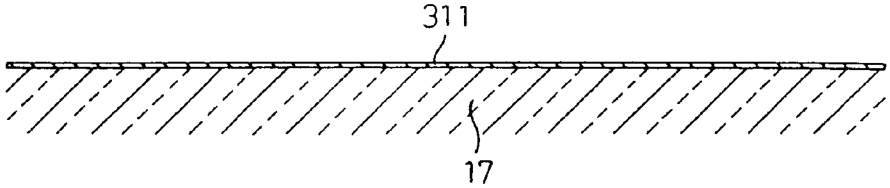


Fig.53B

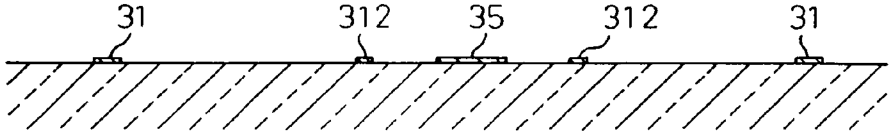


Fig.53C

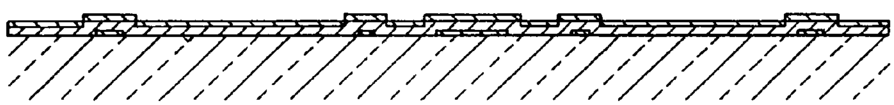


Fig.53D

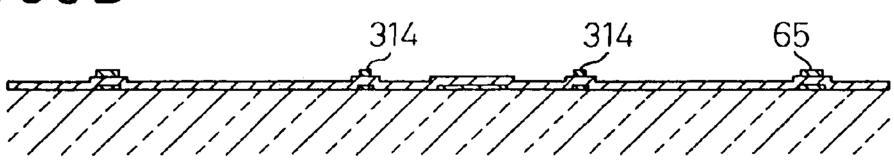


Fig.53E

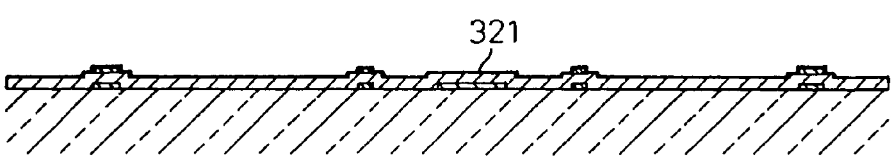


Fig.53F

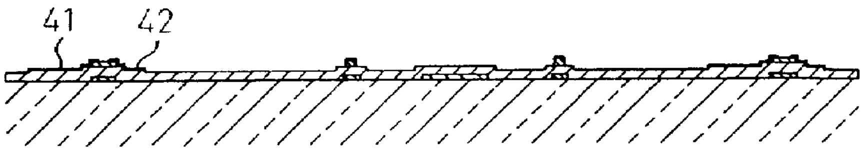


Fig.53G

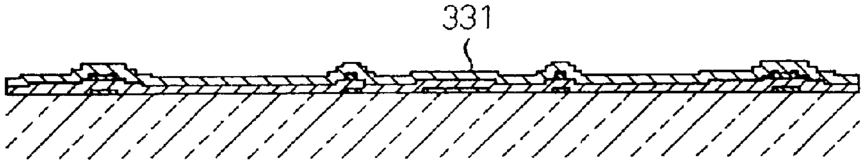


Fig.53H

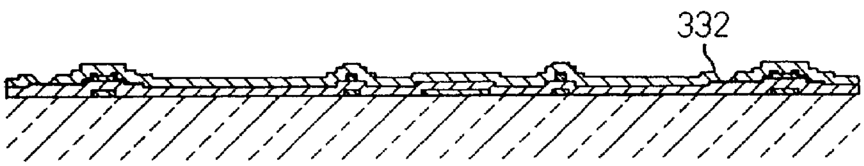


Fig.53I

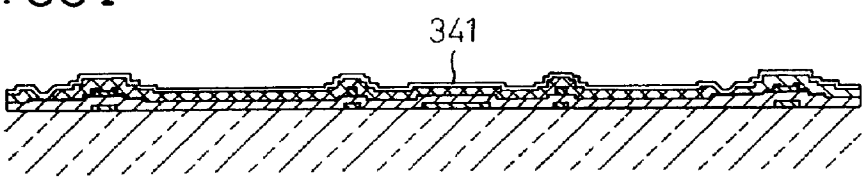


Fig.53J

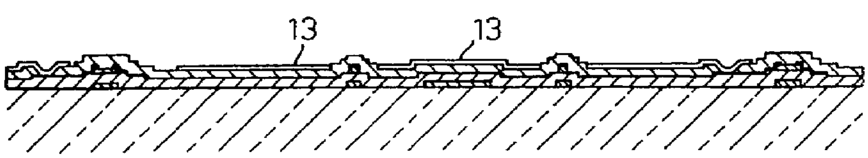
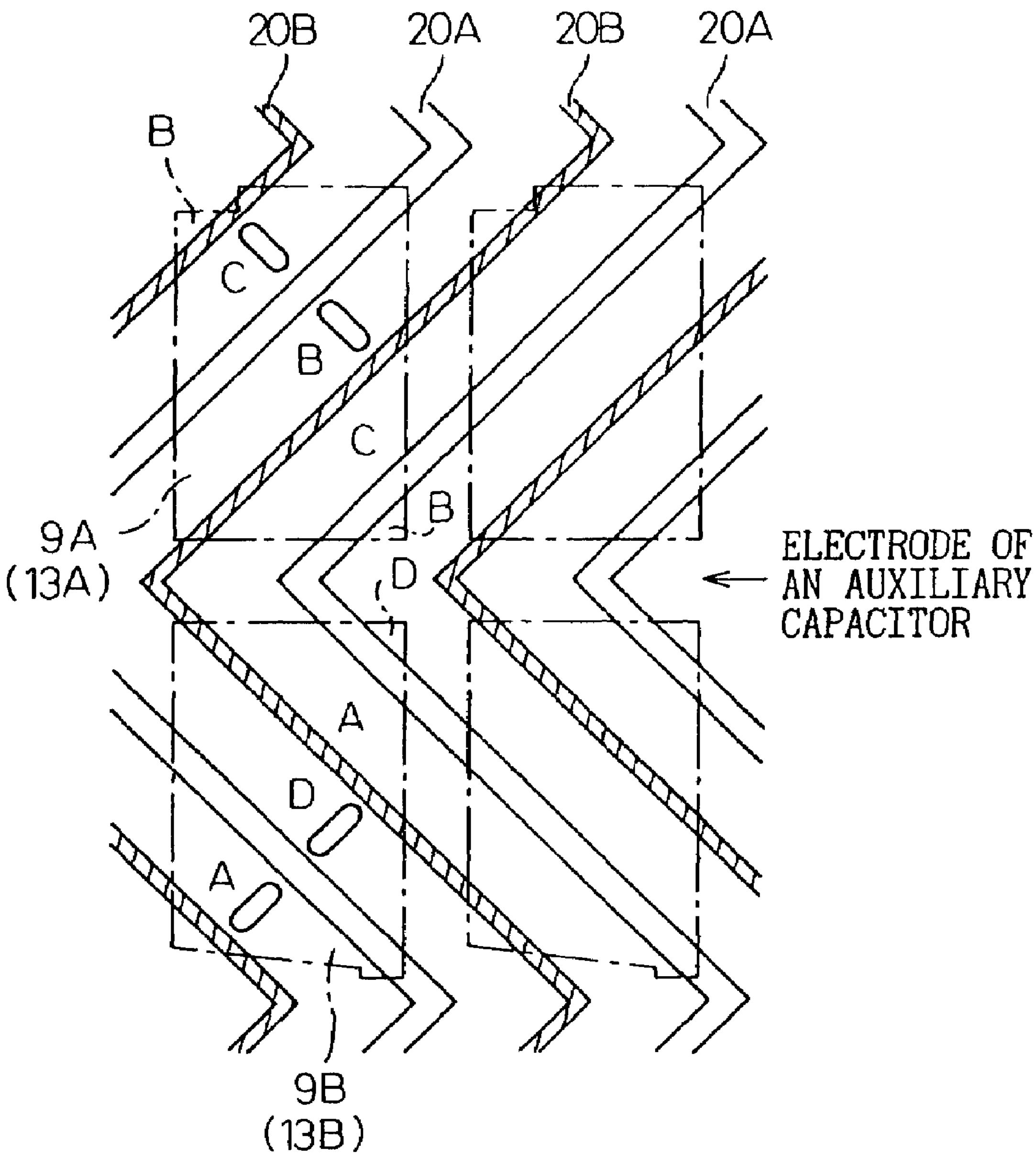


Fig.54



20B
20A
20B
20A
B
C
B
C
B
9A
(13A)
D
ELECTRODE OF
AN AUXILIARY
CAPACITOR
A
D
A
9B
(13B)

Fig.55

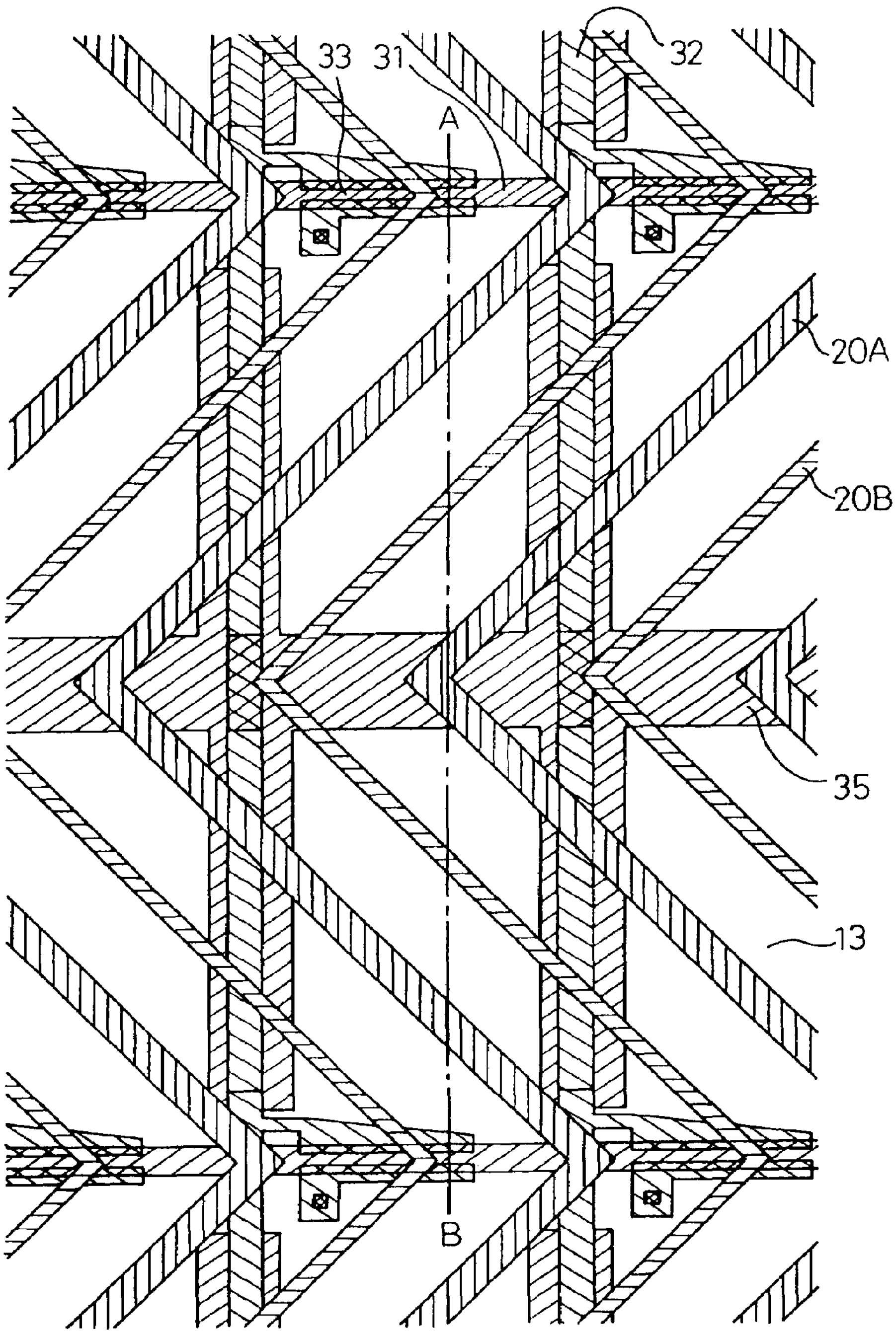


Fig.56

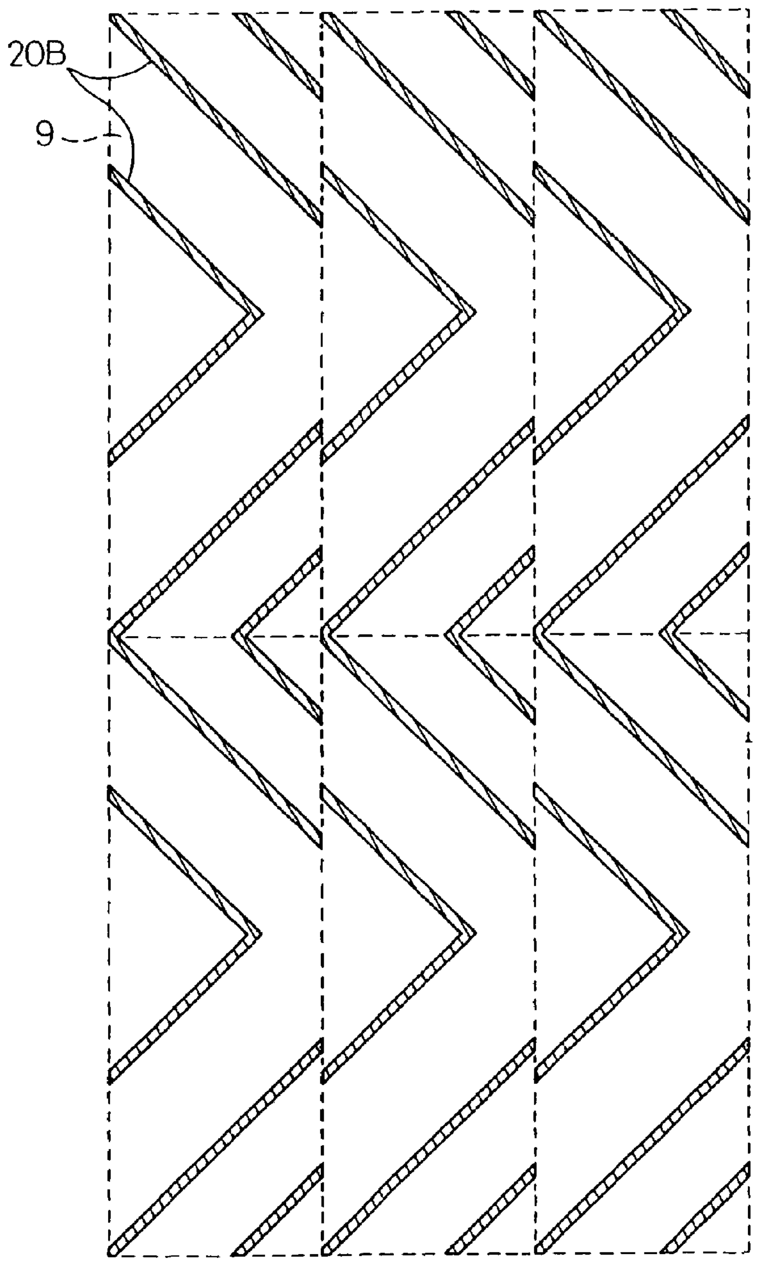


Fig.57A

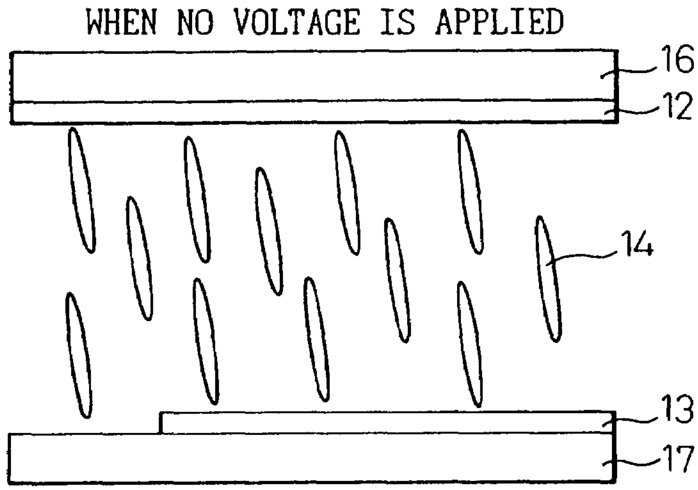


Fig.57B

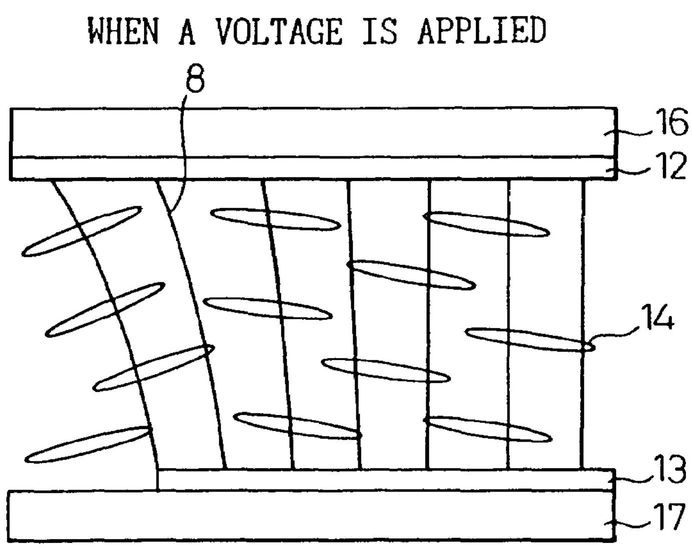


Fig.58

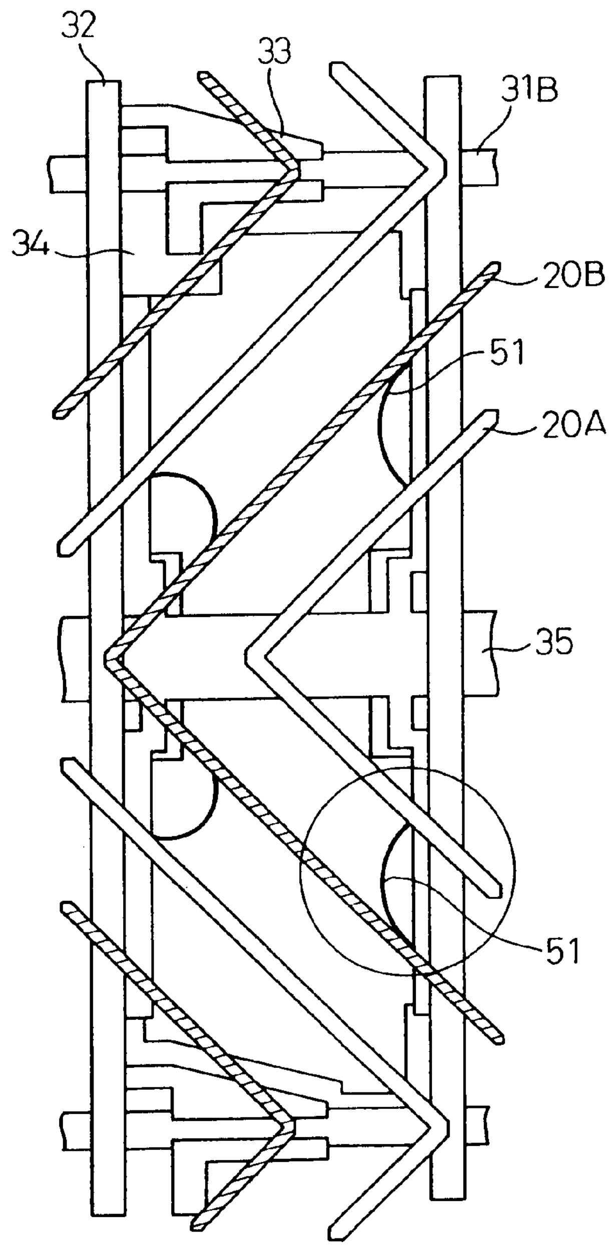


Fig. 59

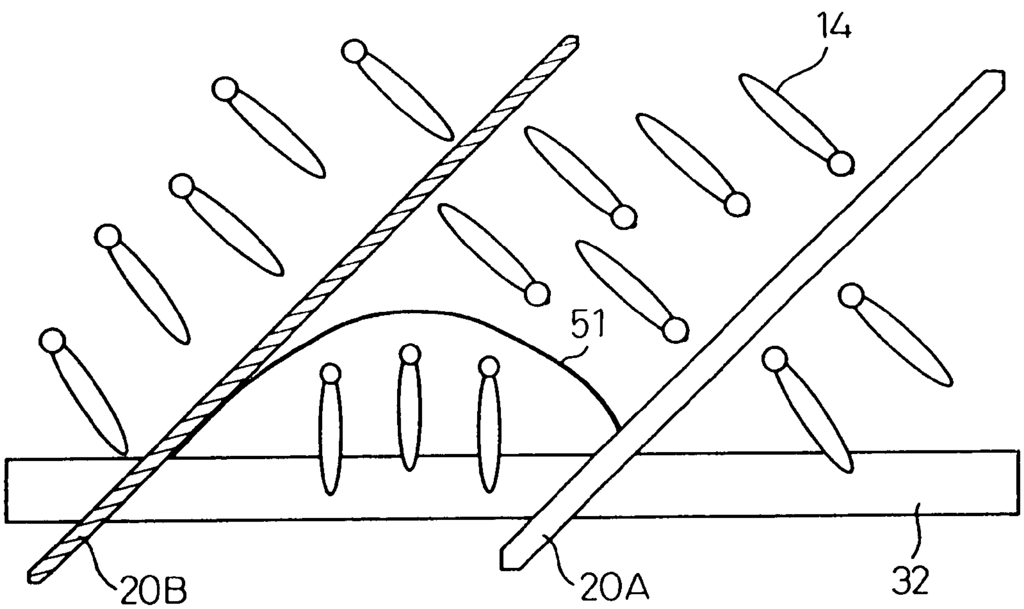


Fig. 60

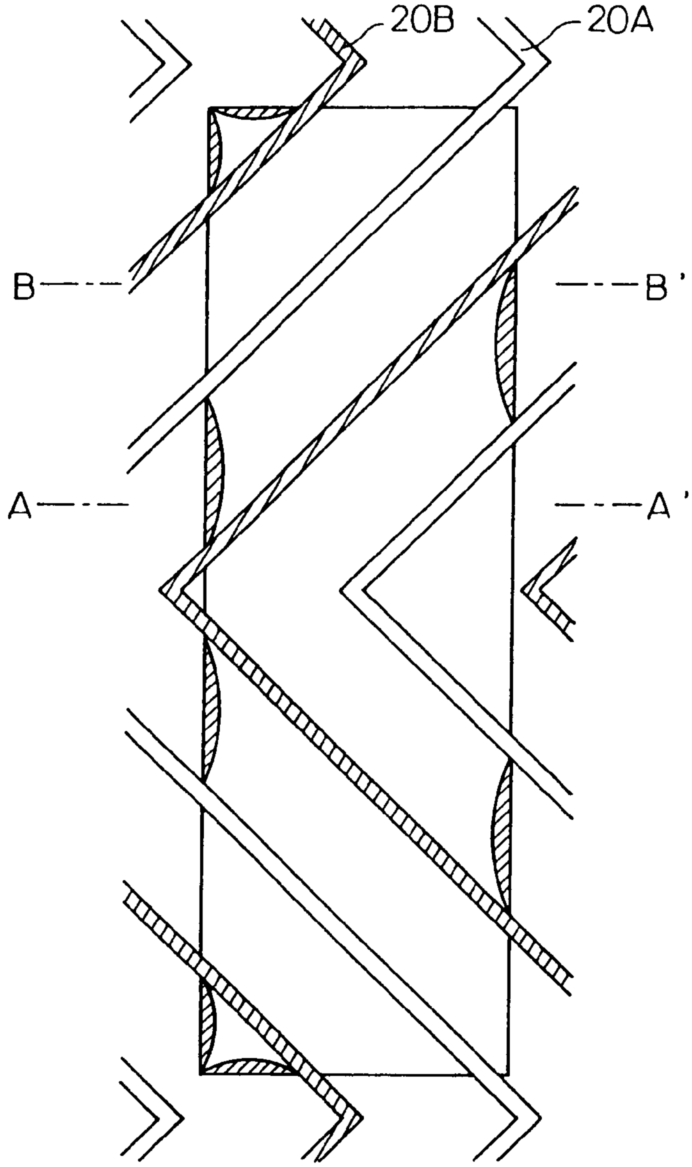


Fig.61A

A − A'

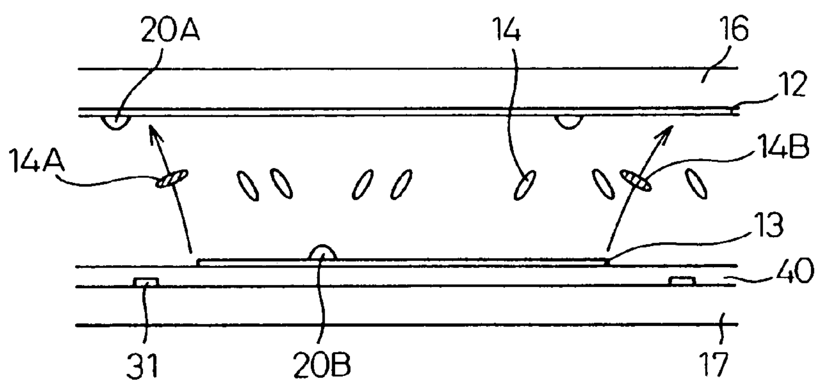


Fig.61B

B − B'

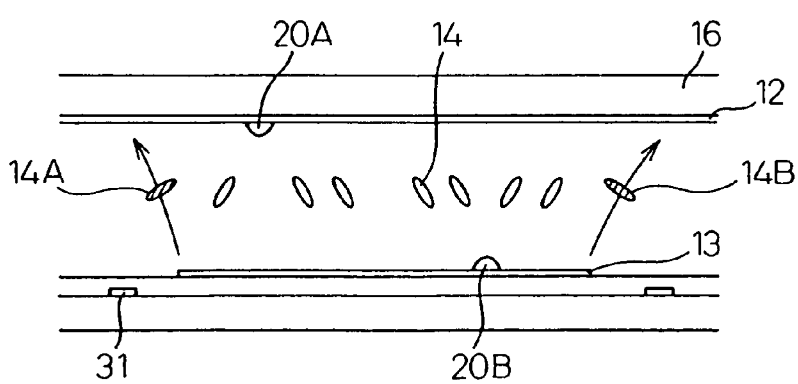


Fig.62A

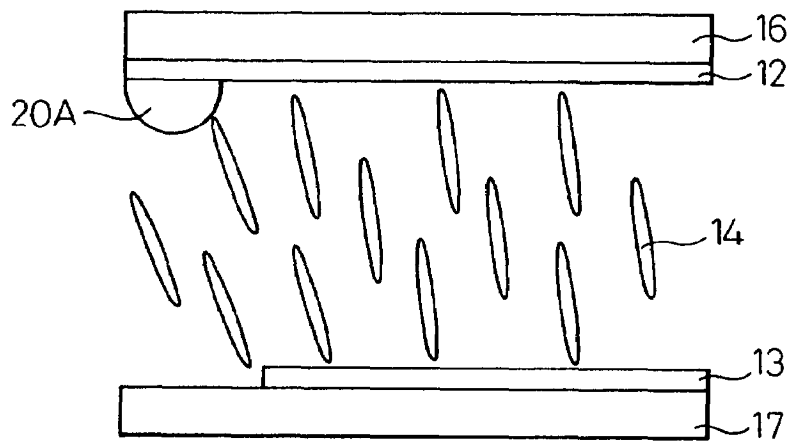


Fig.62B

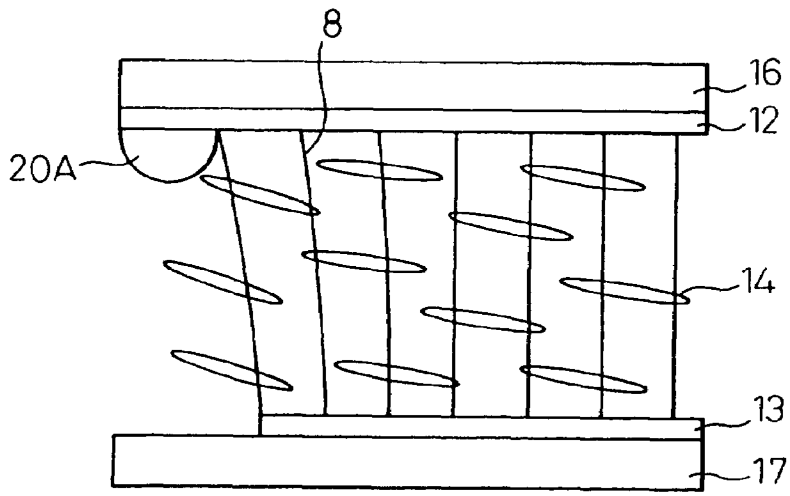


Fig. 63

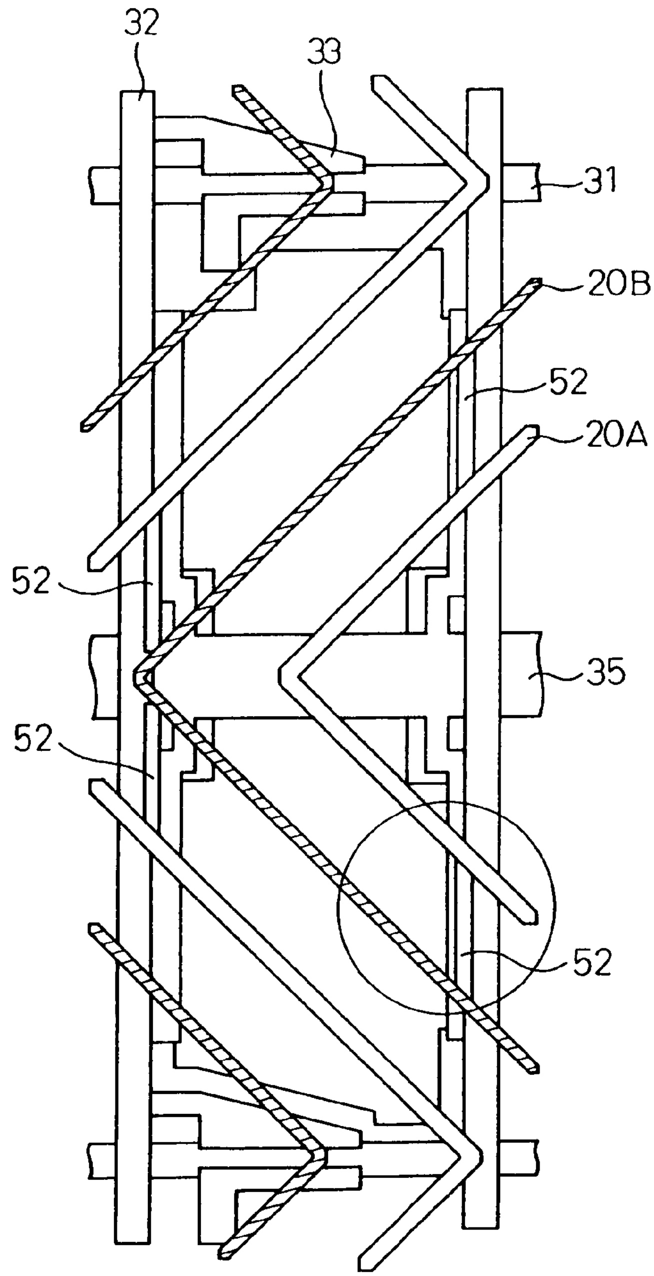


Fig.64

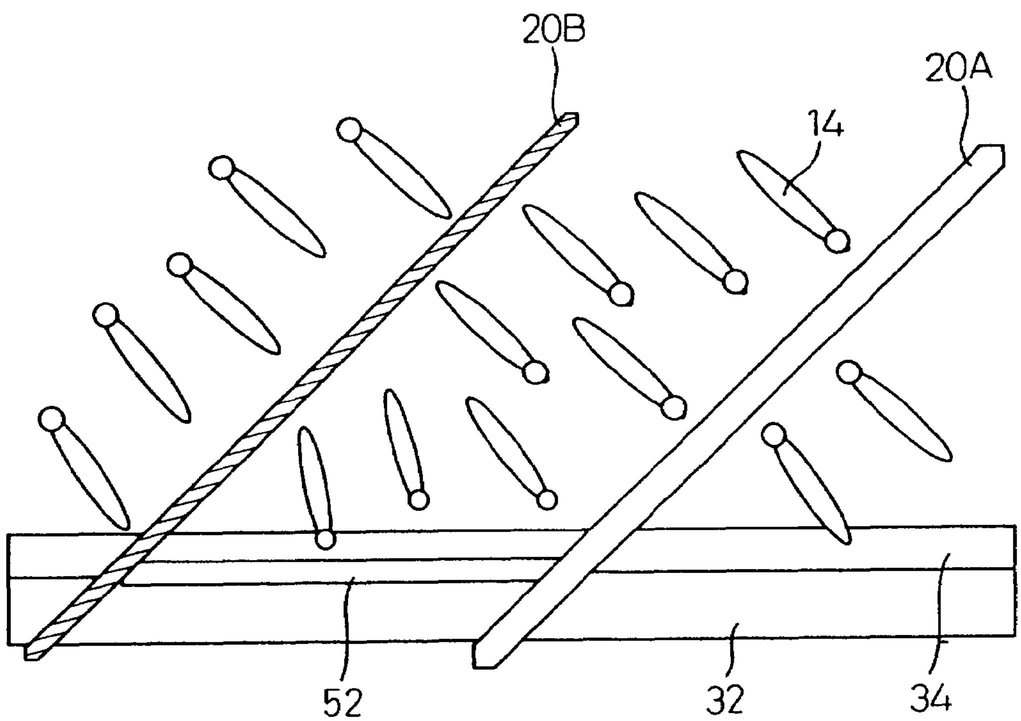


Fig.65A

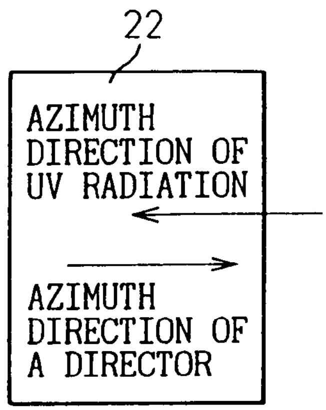


Fig.65B

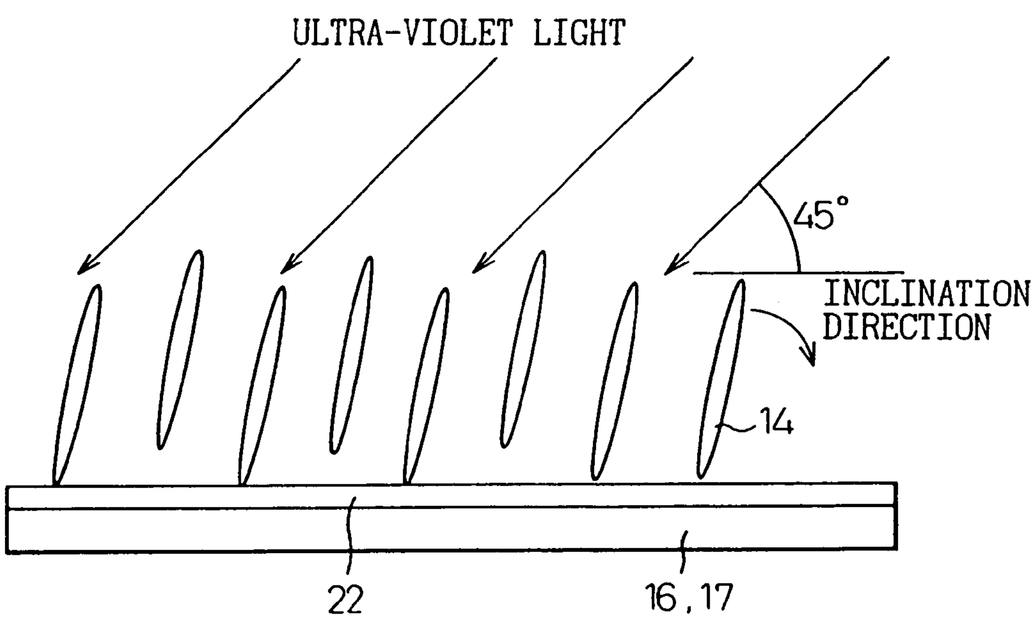


Fig.66

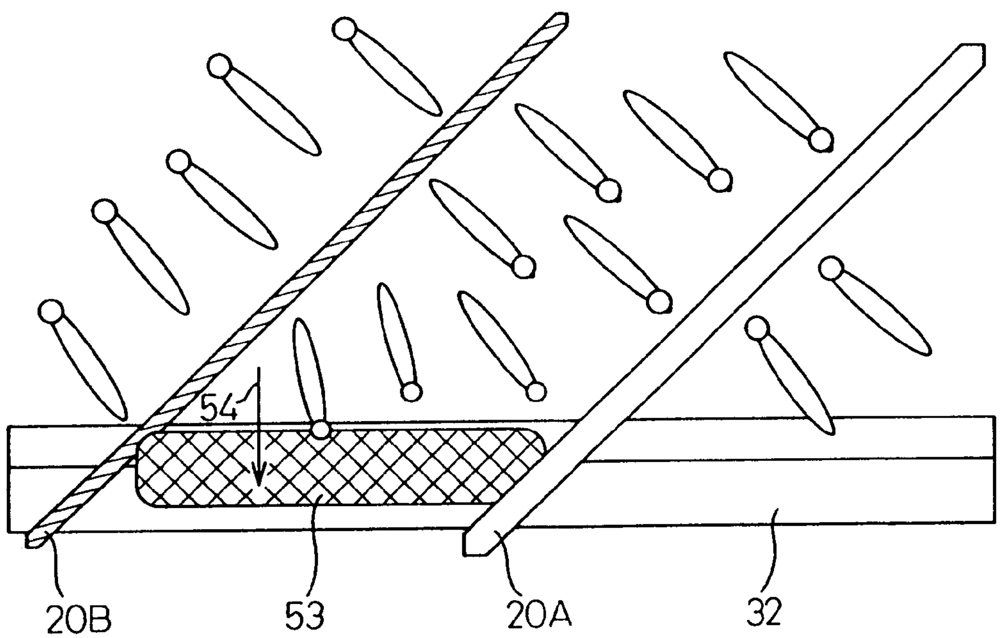


Fig.67A

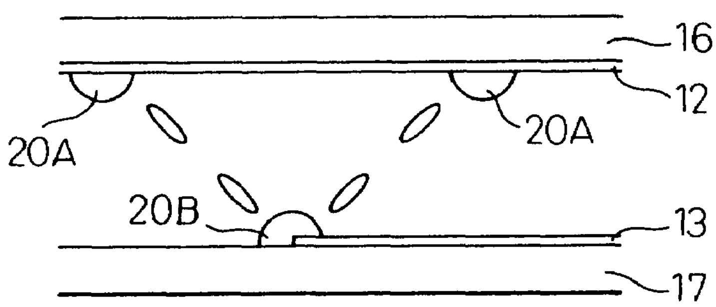


Fig.67B

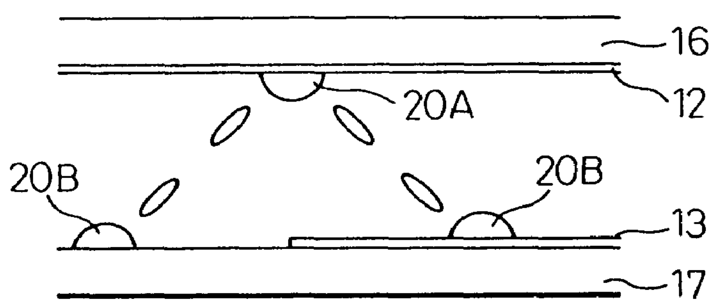


Fig.67C

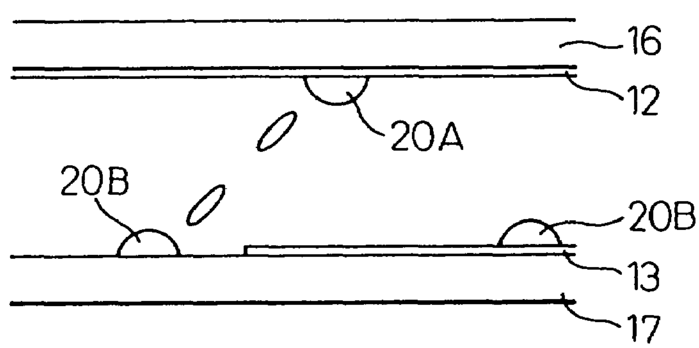


Fig.68

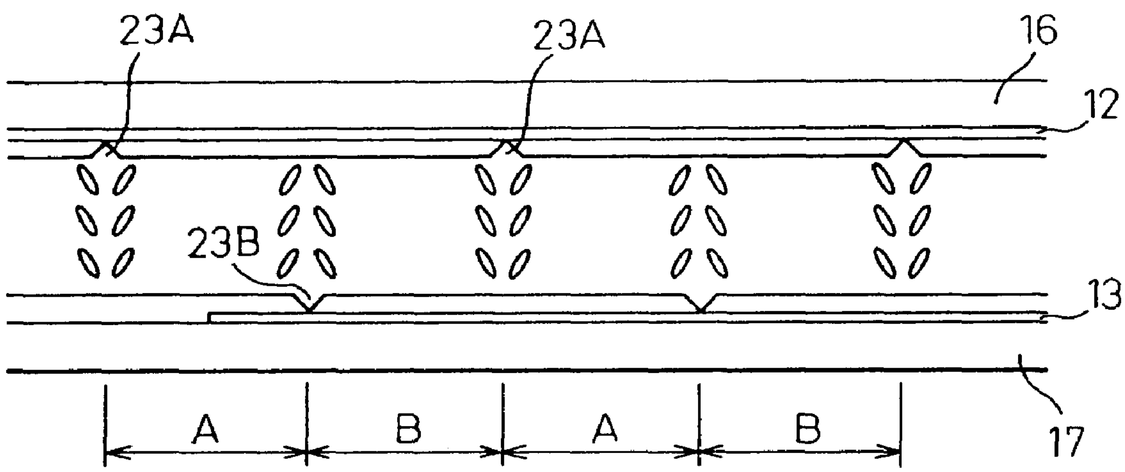


Fig.69A

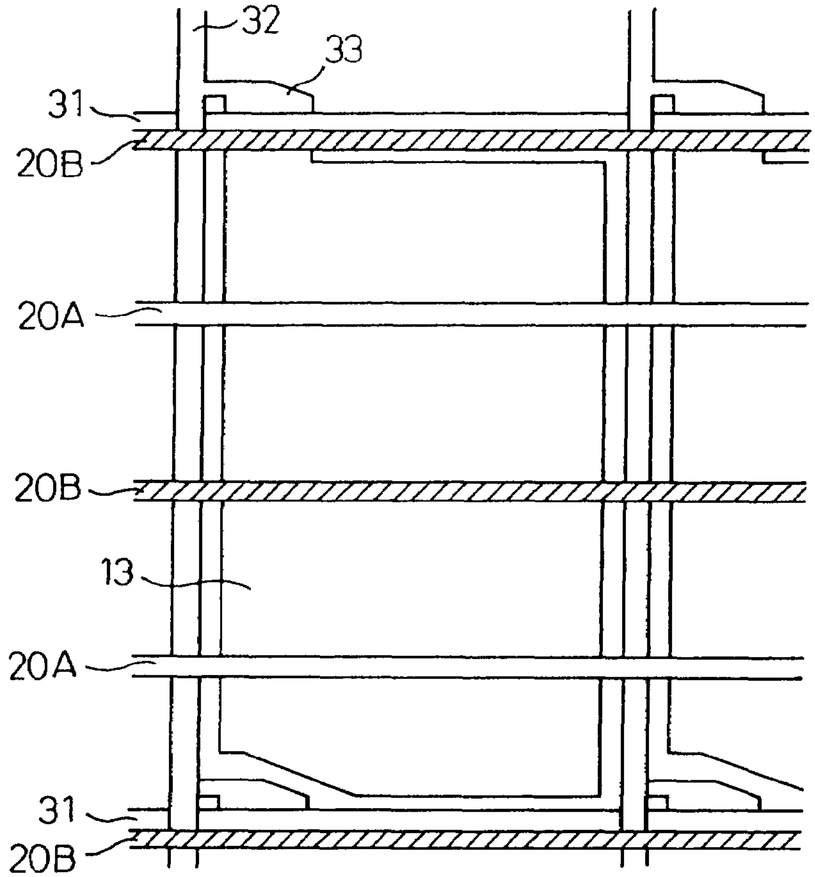


Fig.69B

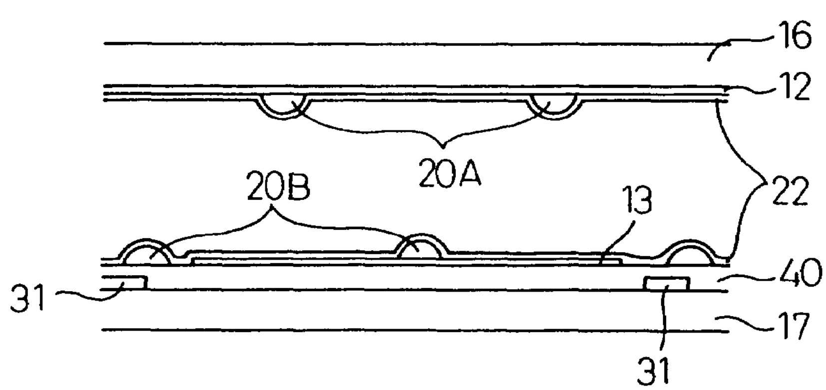


Fig.70A

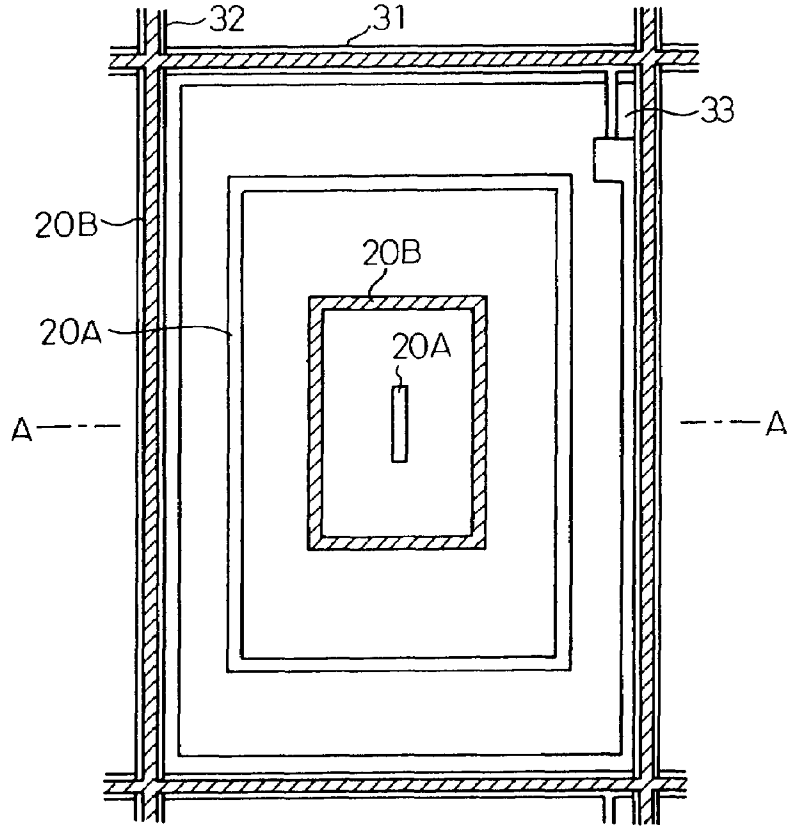


Fig.70B

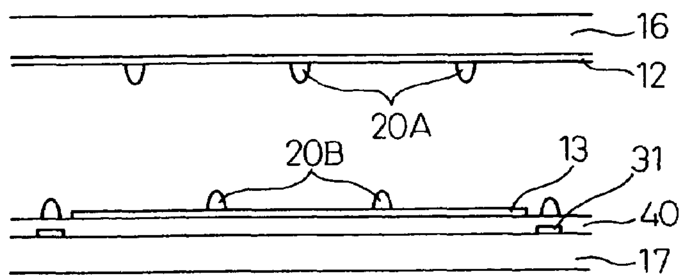


Fig.71

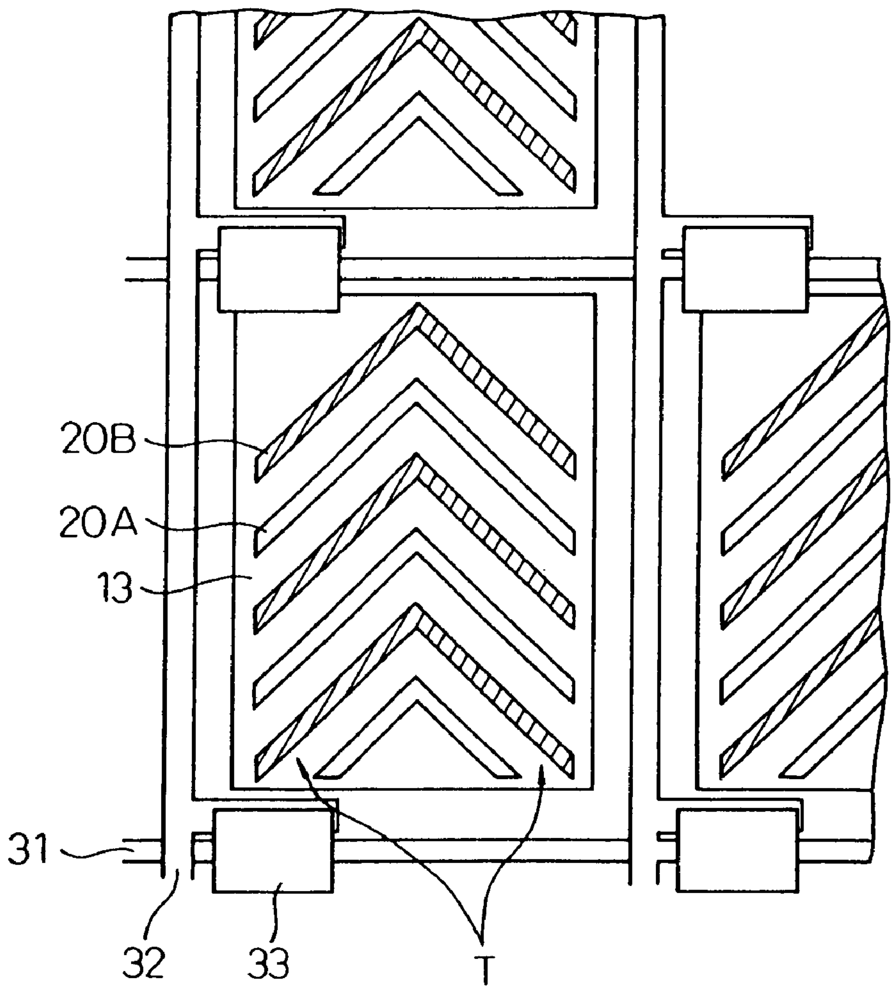


Fig.72

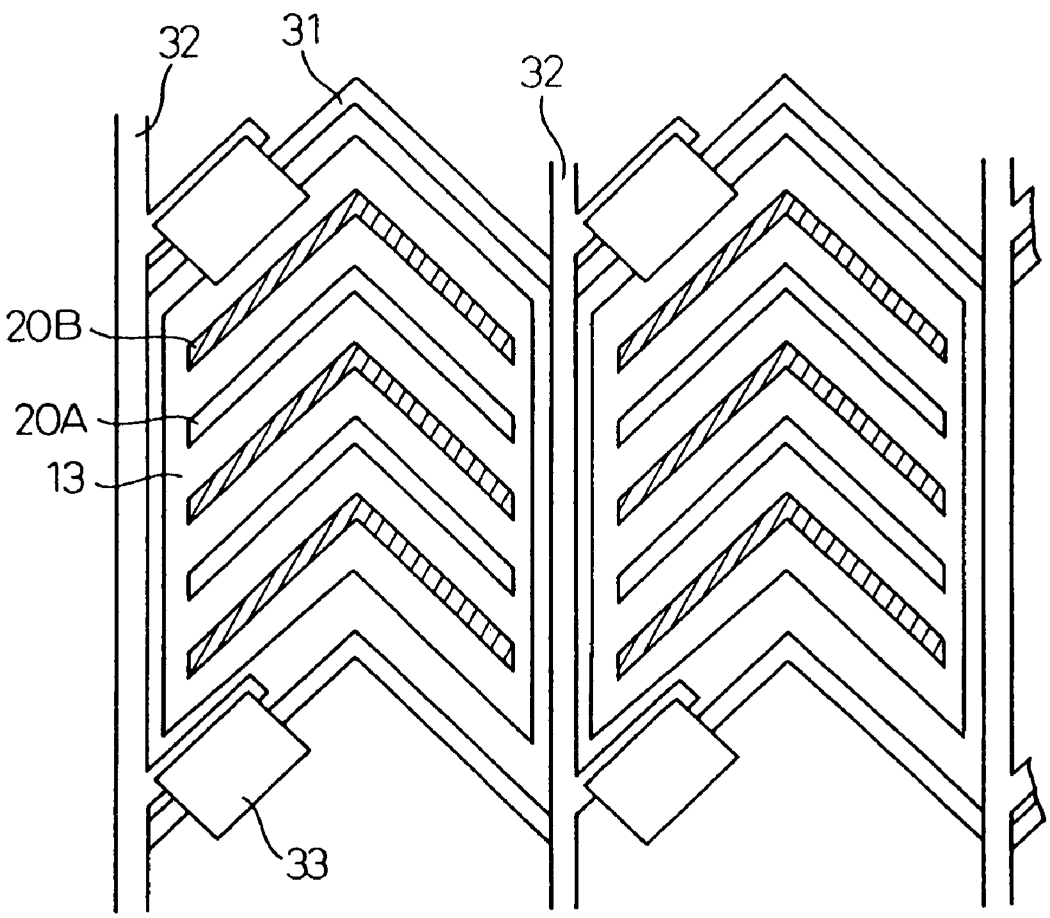


Fig. 73

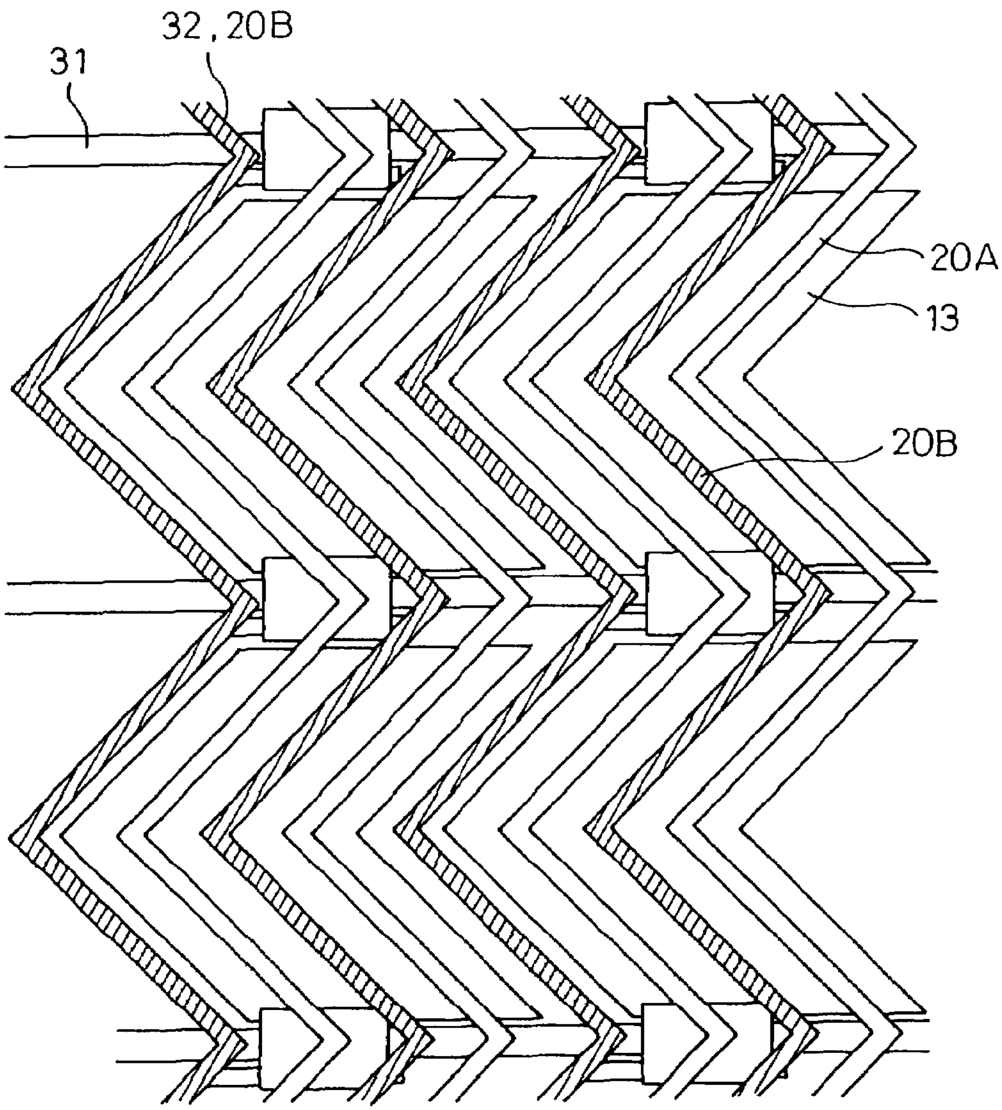


Fig.74

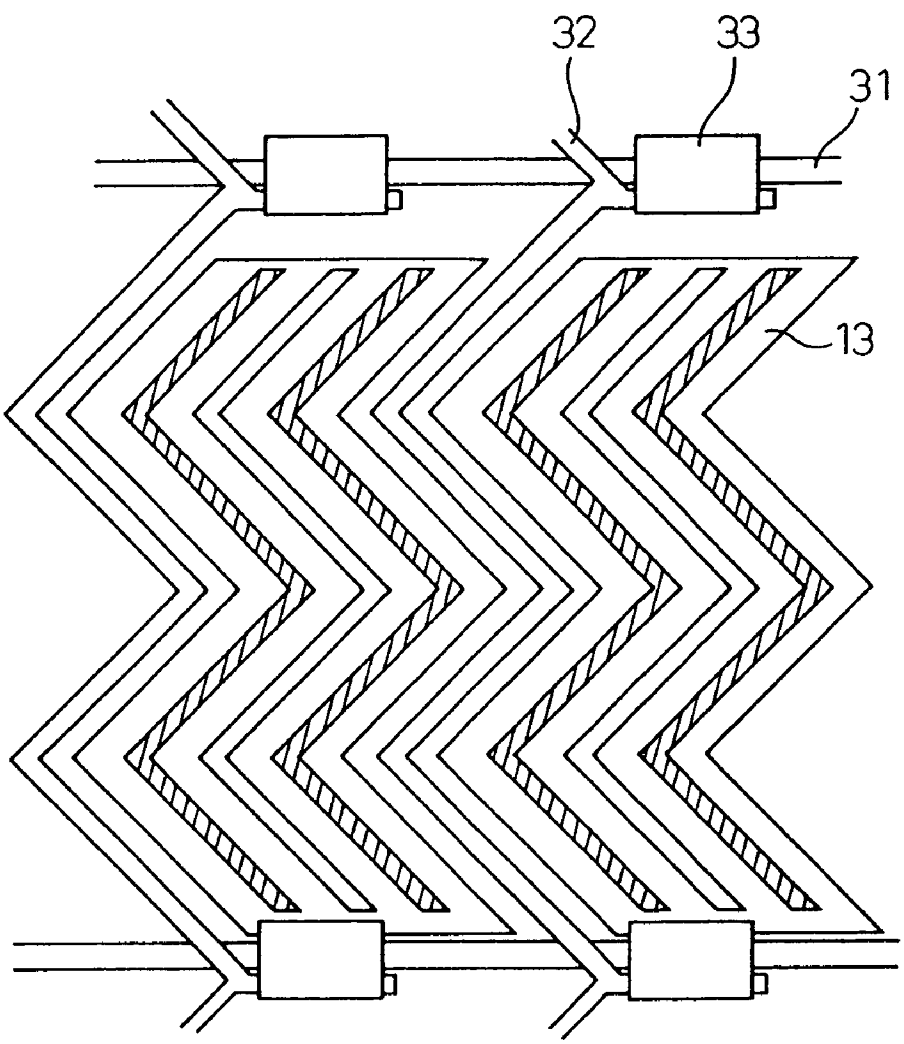


Fig.75

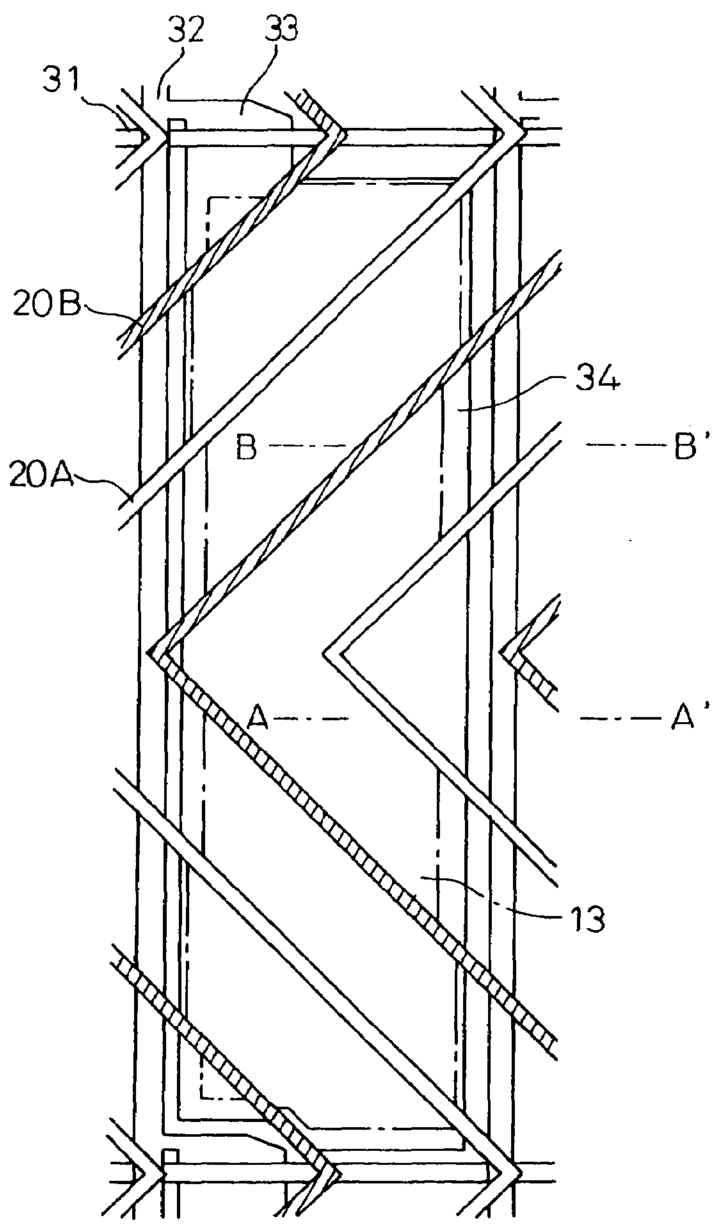


Fig.76A

A-A'

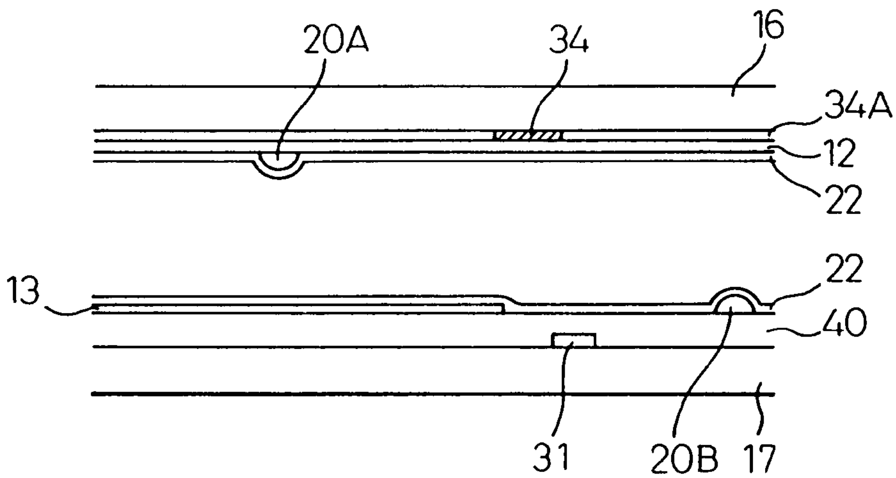


Fig.76B

B-B'

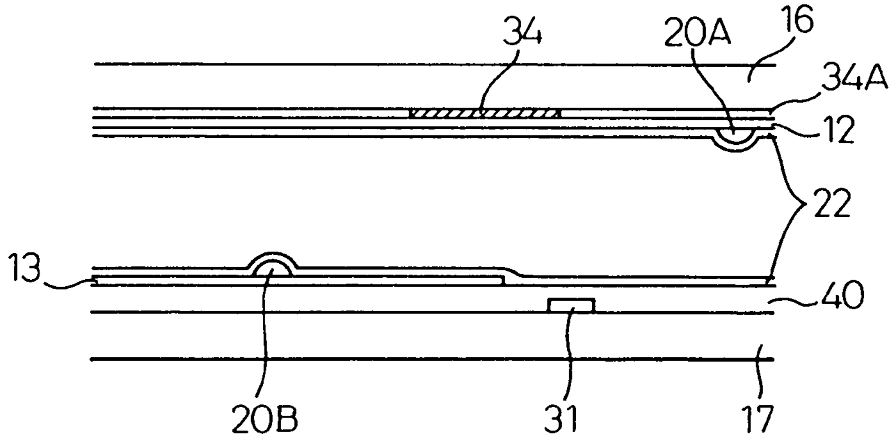


Fig.77A

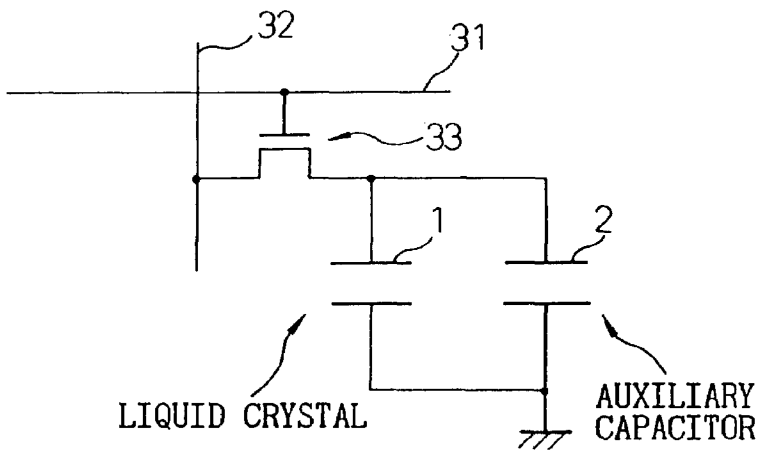


Fig.77B

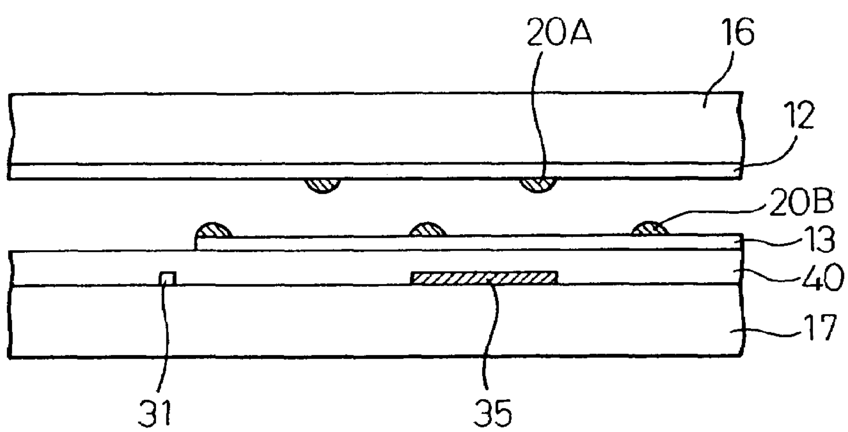


Fig.78A

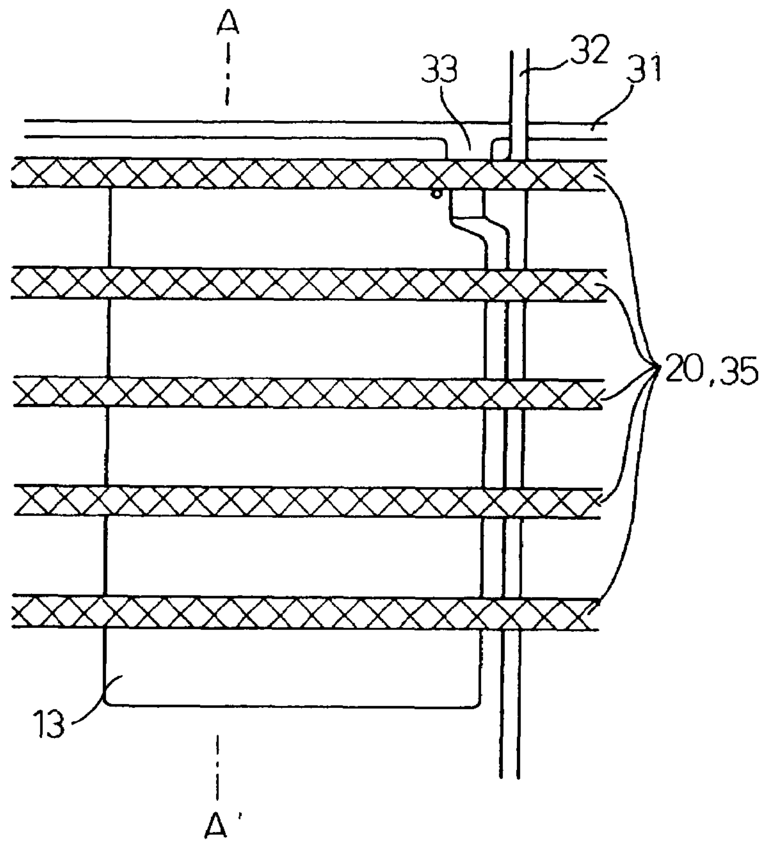


Fig.78B

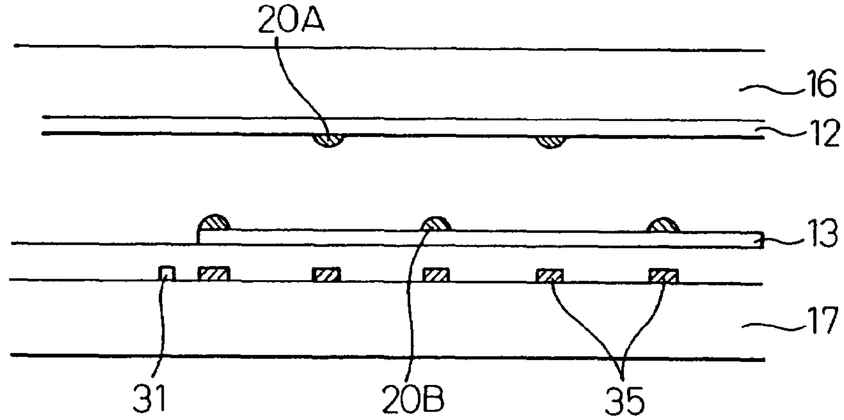


Fig.79A

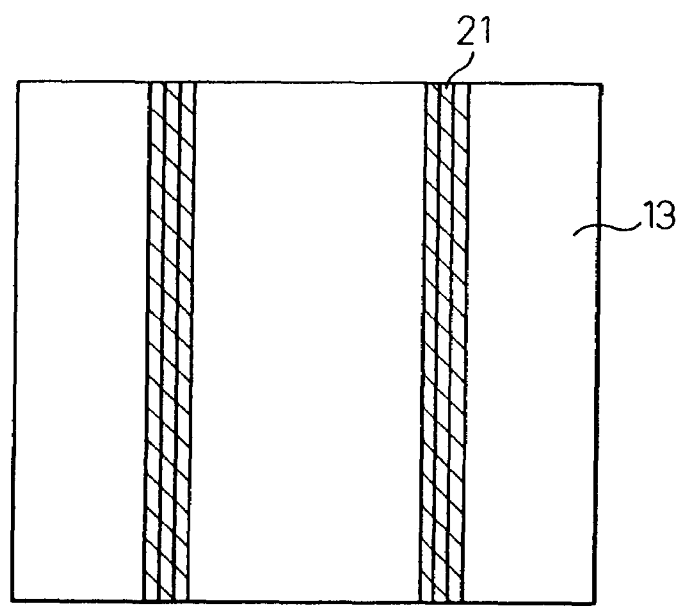


Fig.79B

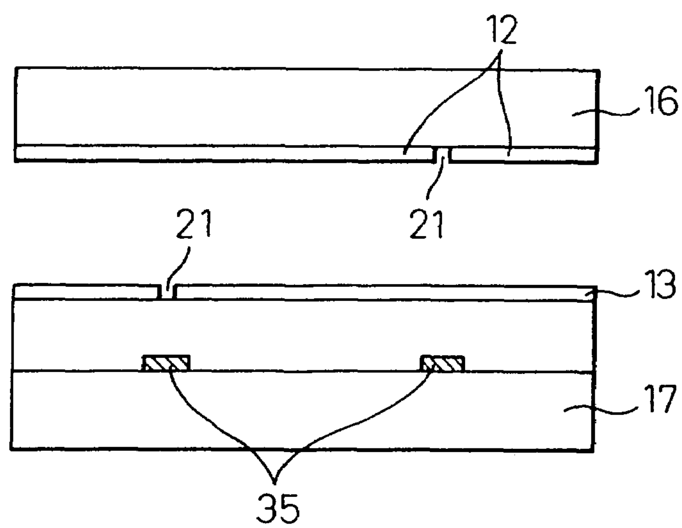


Fig.80A

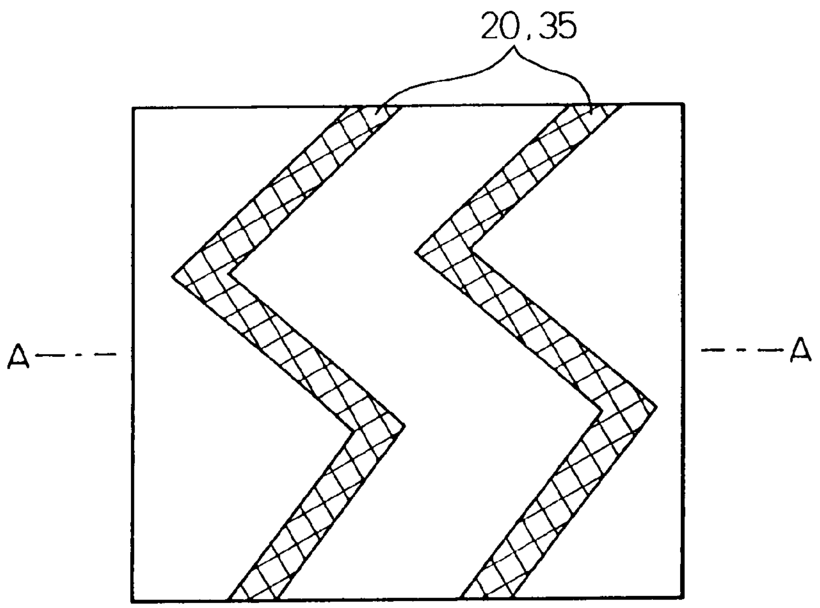


Fig.80B

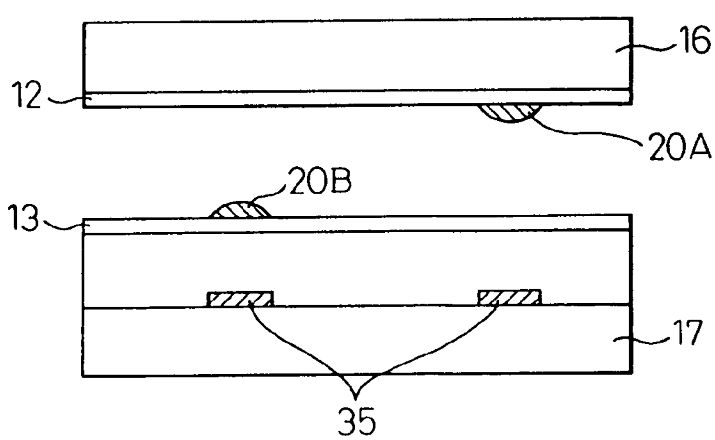


Fig.81A

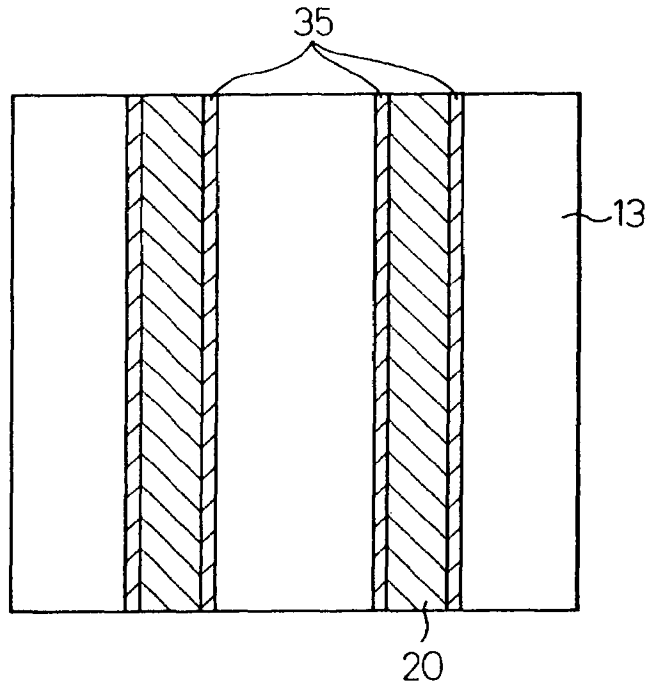


Fig.81B

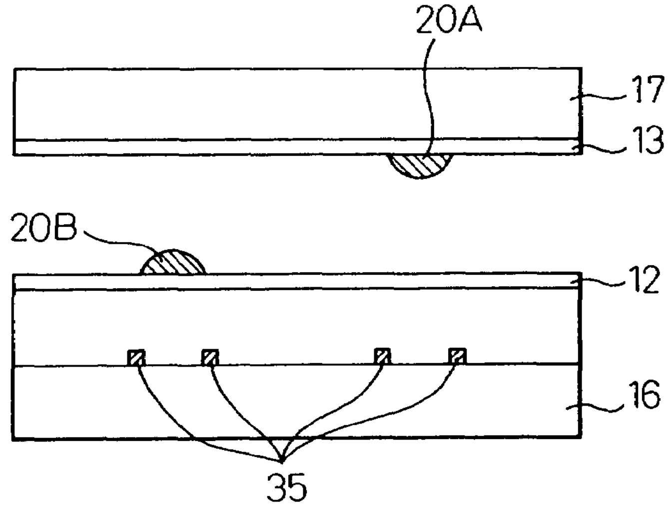


Fig. 82

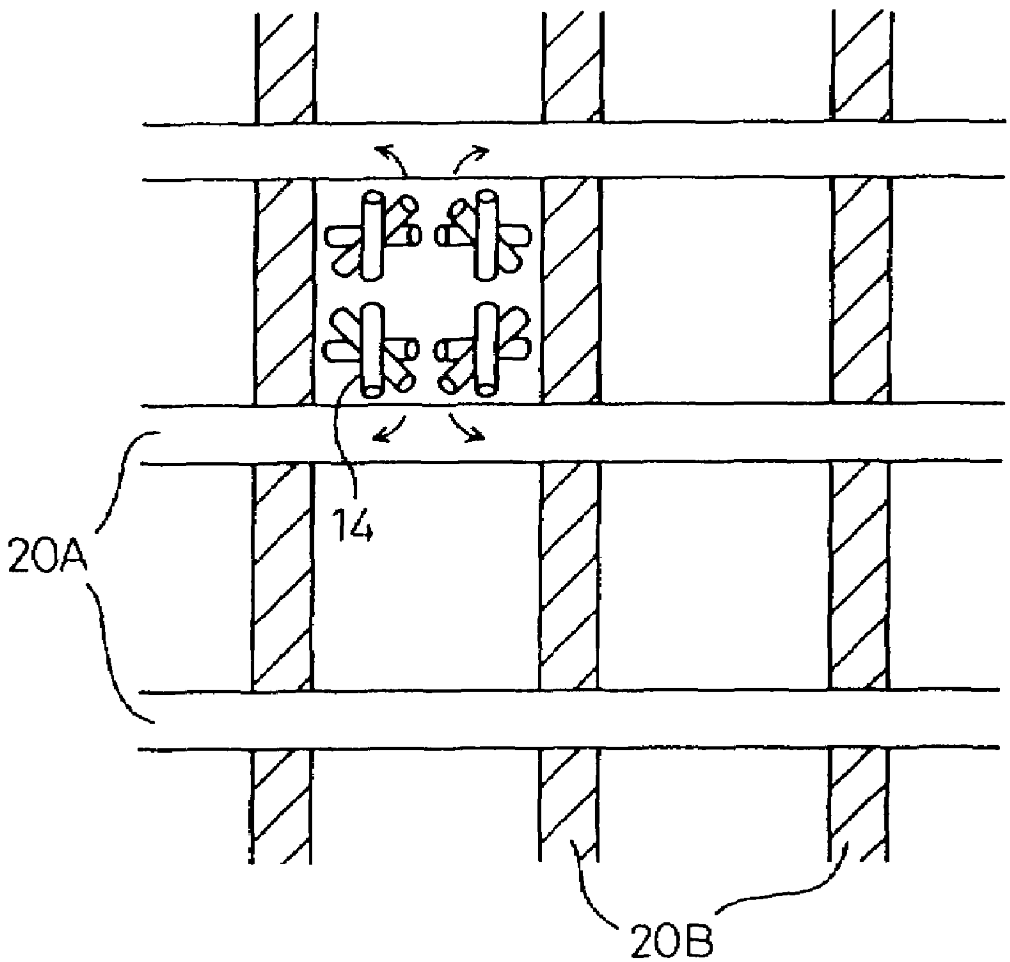


Fig.83A

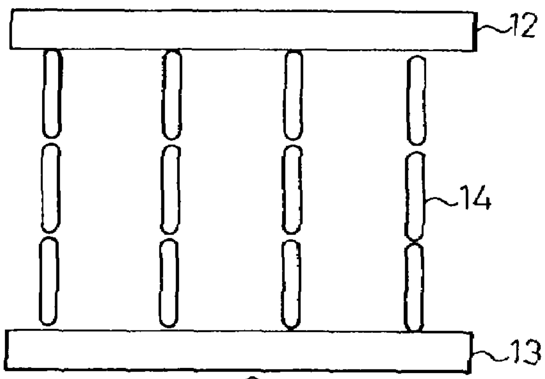


Fig.83B

Fig.83C

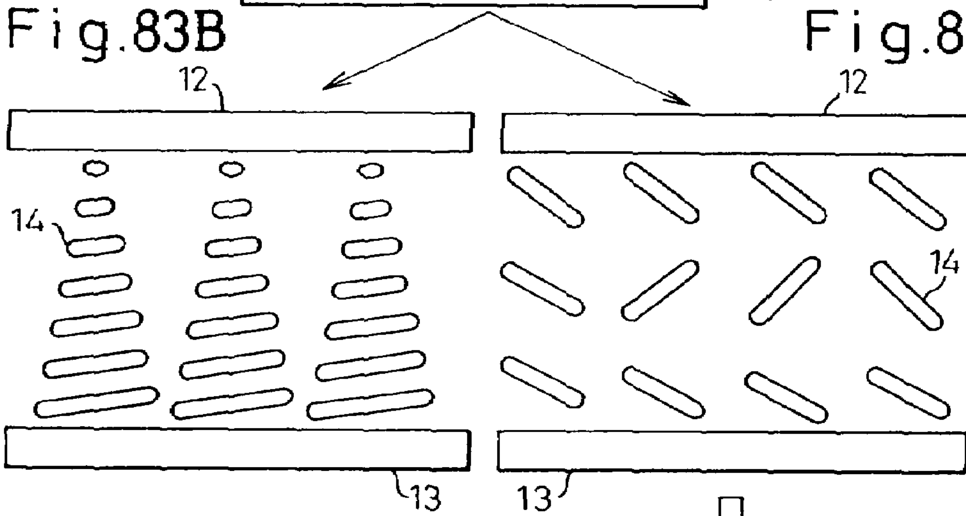


Fig.83D

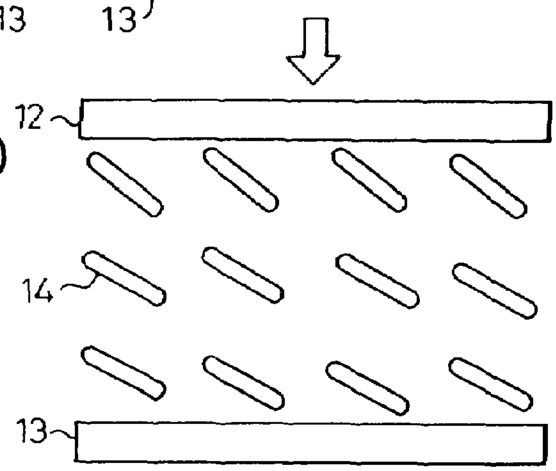


Fig.84

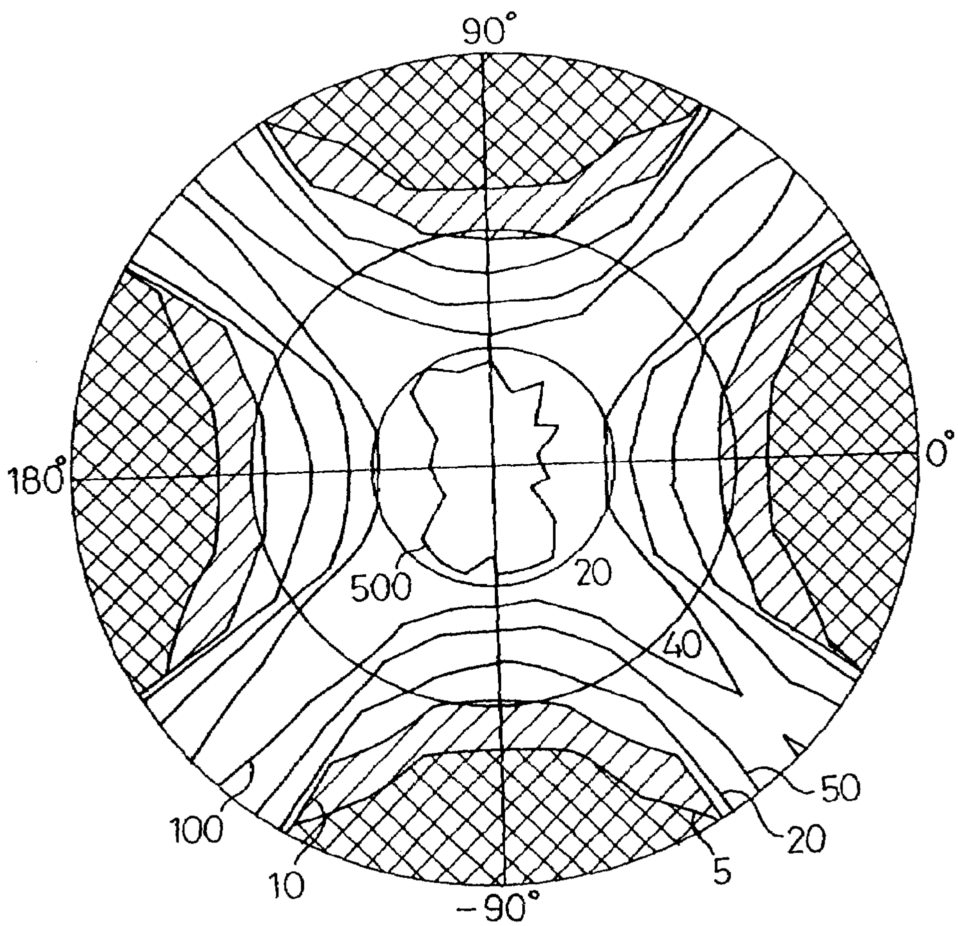


Fig.85A

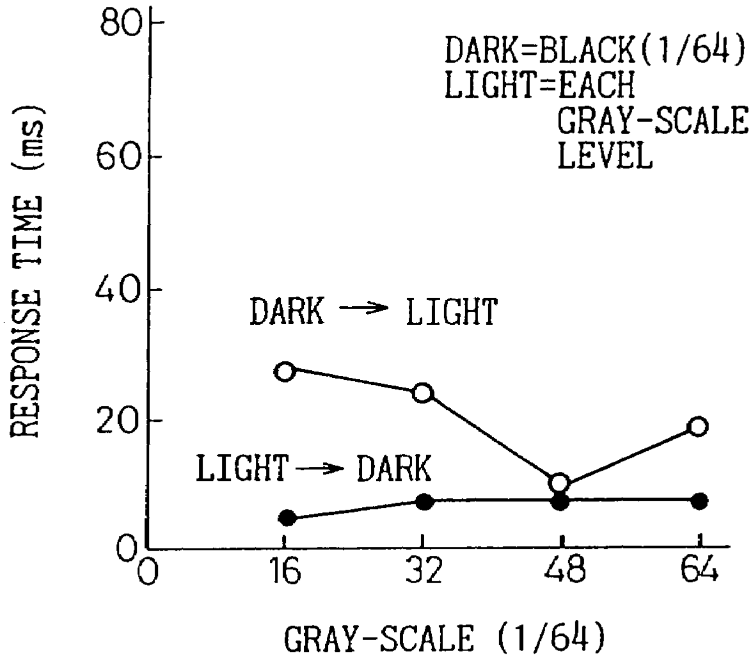


Fig.85B

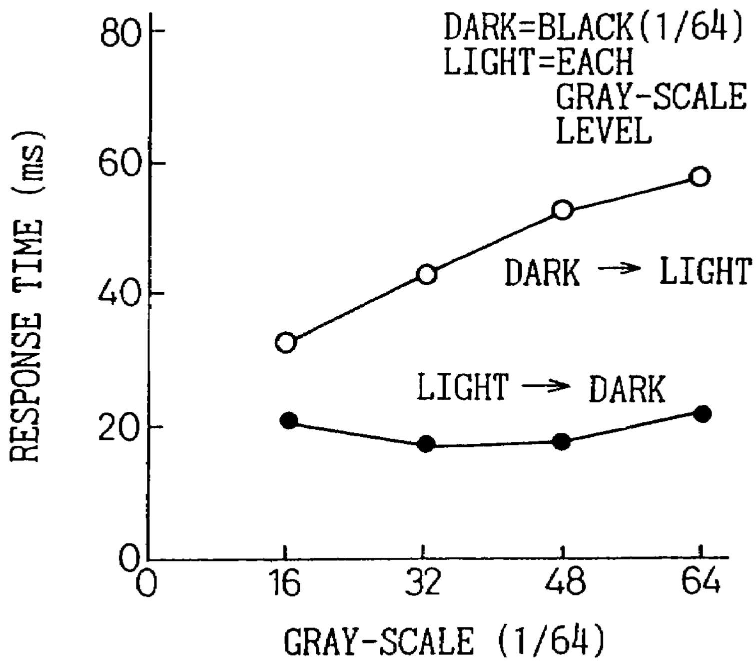


Fig.85C

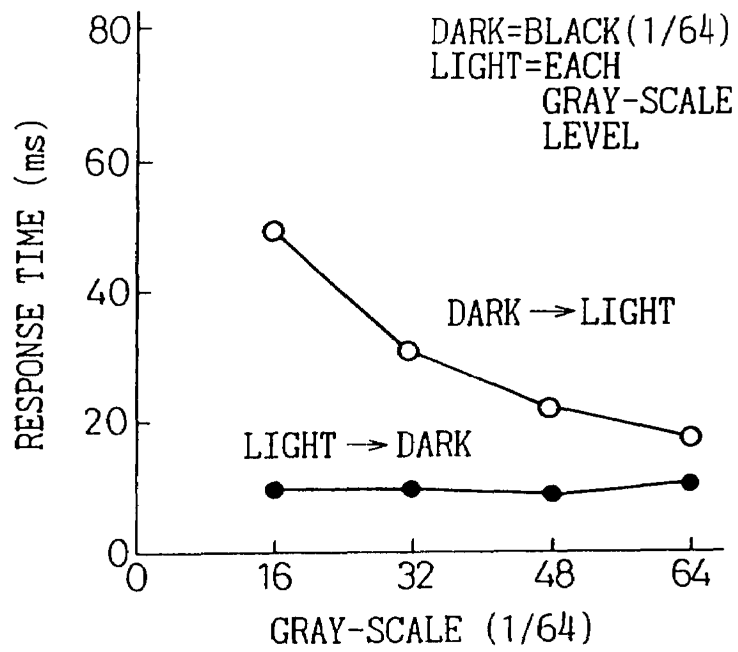


Fig.85D

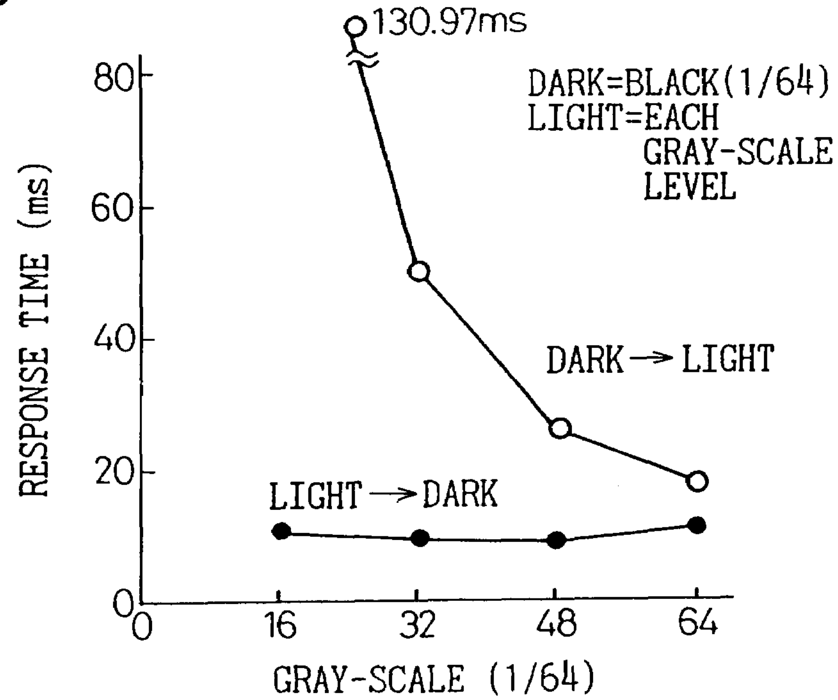


Fig.86A

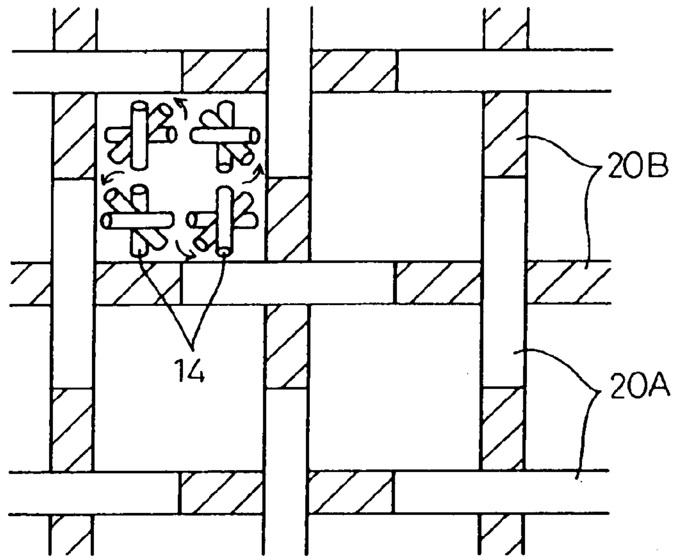


Fig.86B

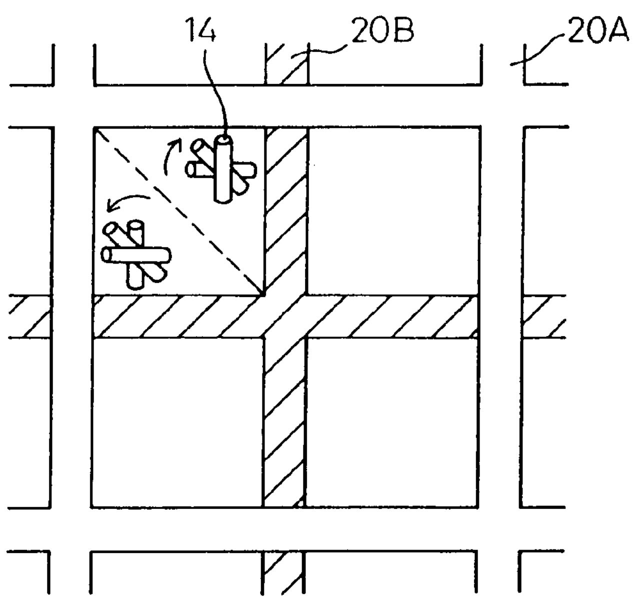


Fig. 87

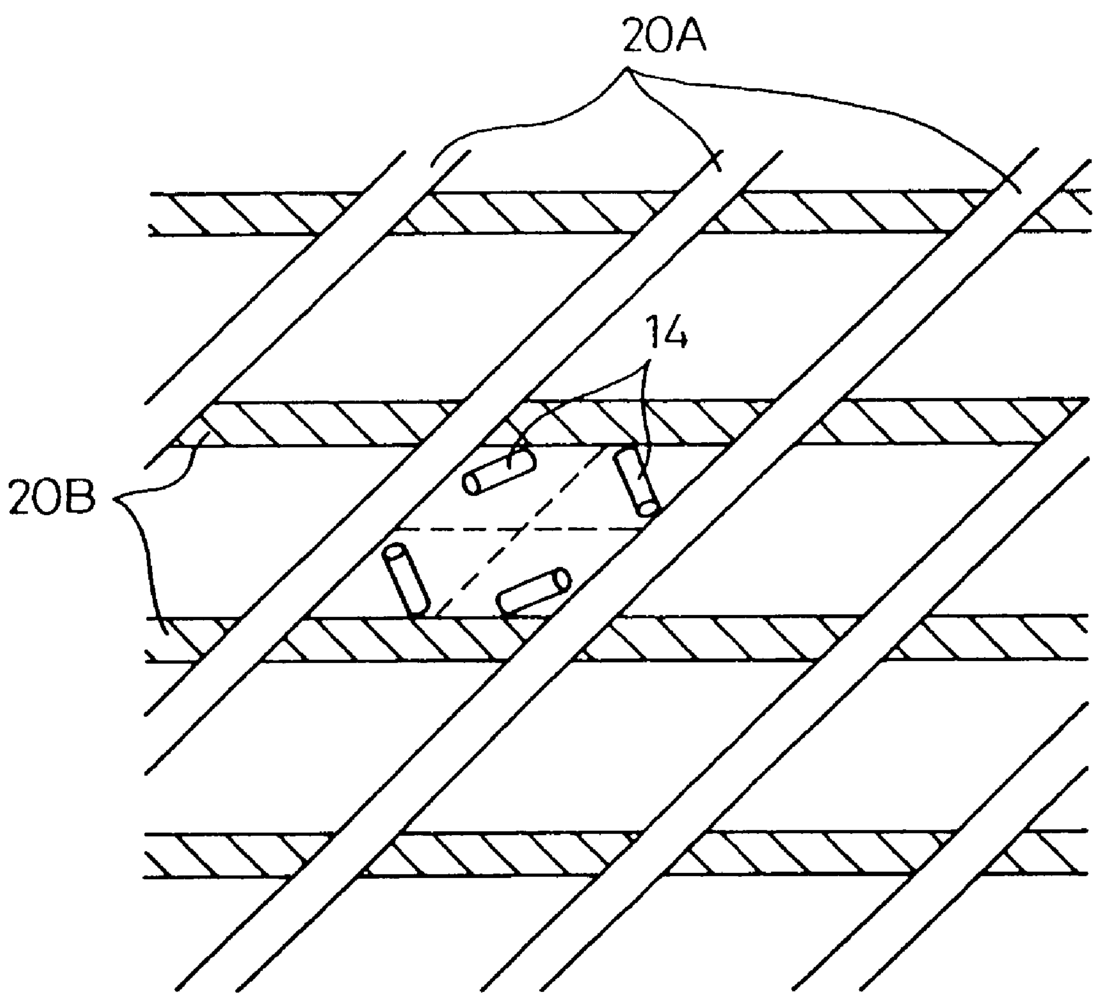


Fig.88

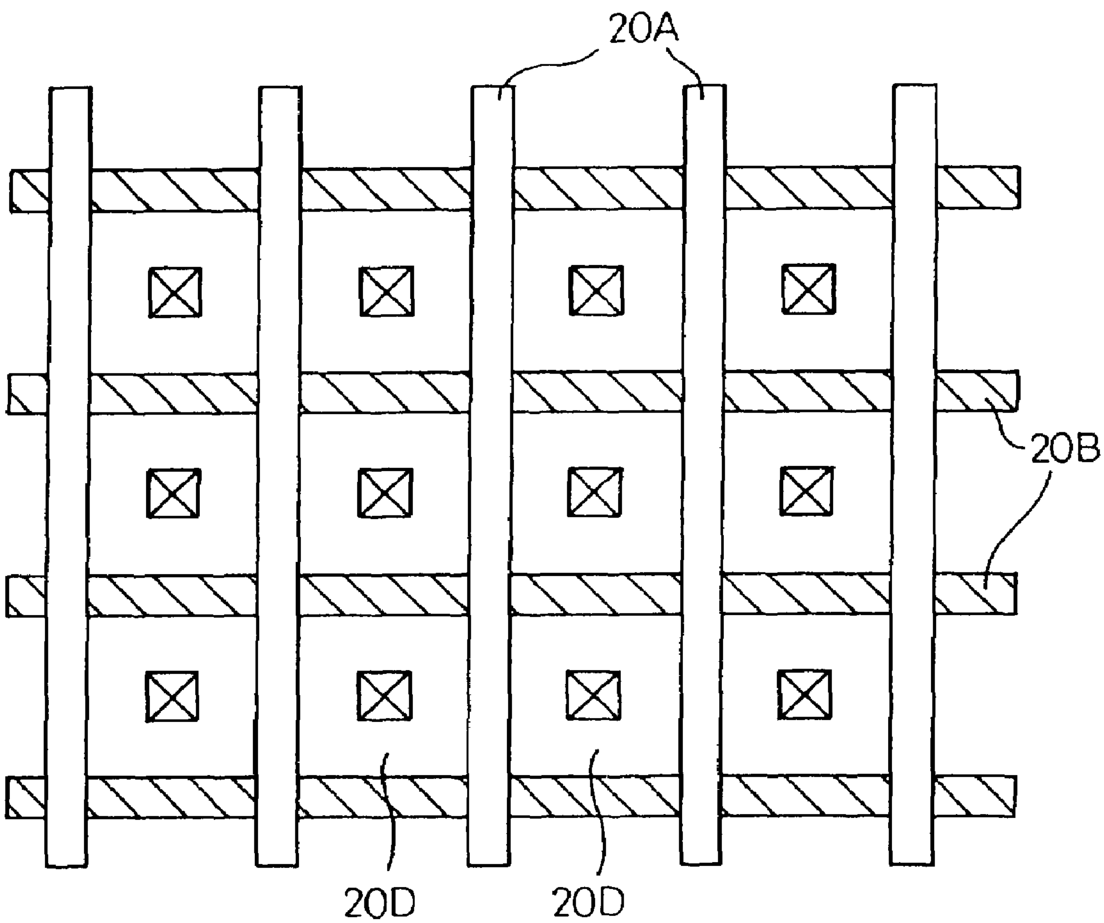


Fig.89

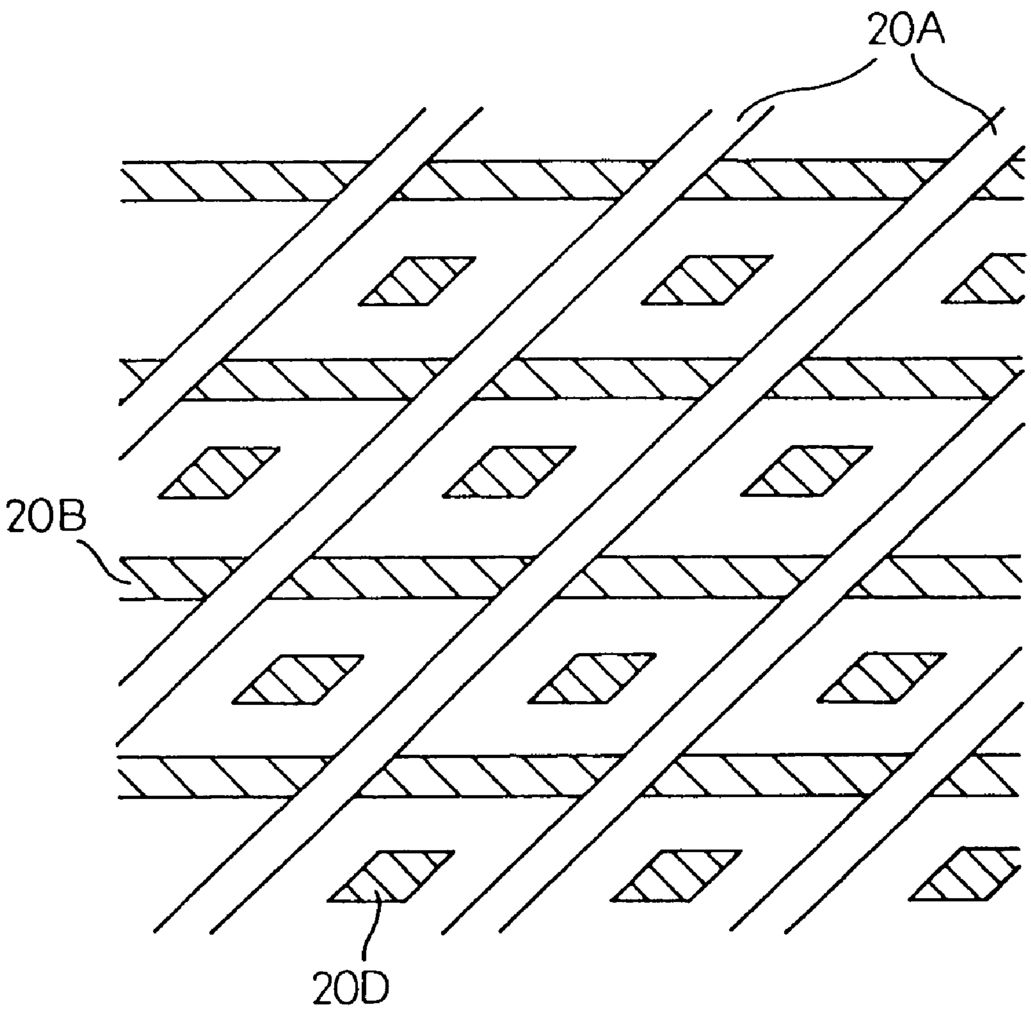


Fig.90A

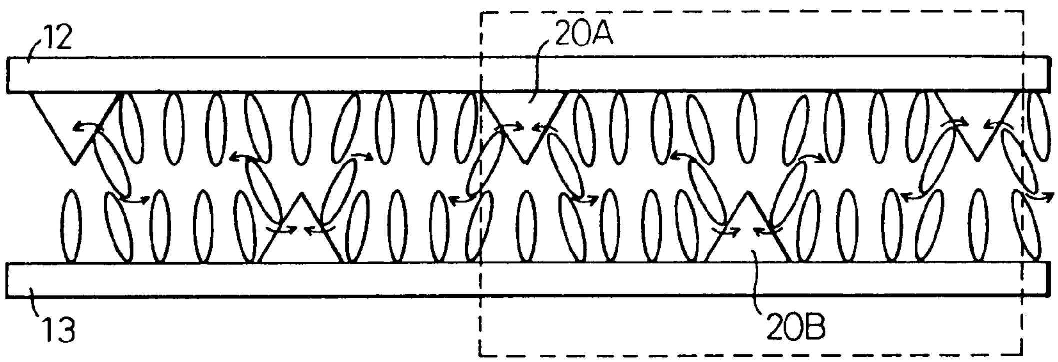


Fig.90B

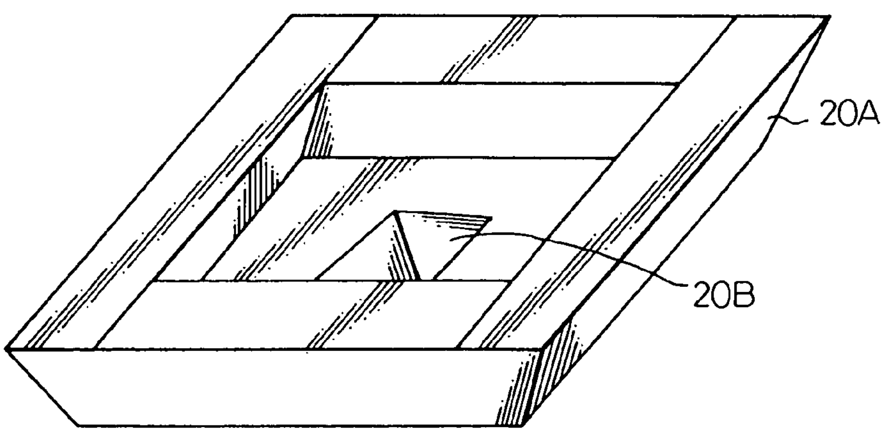


Fig.91

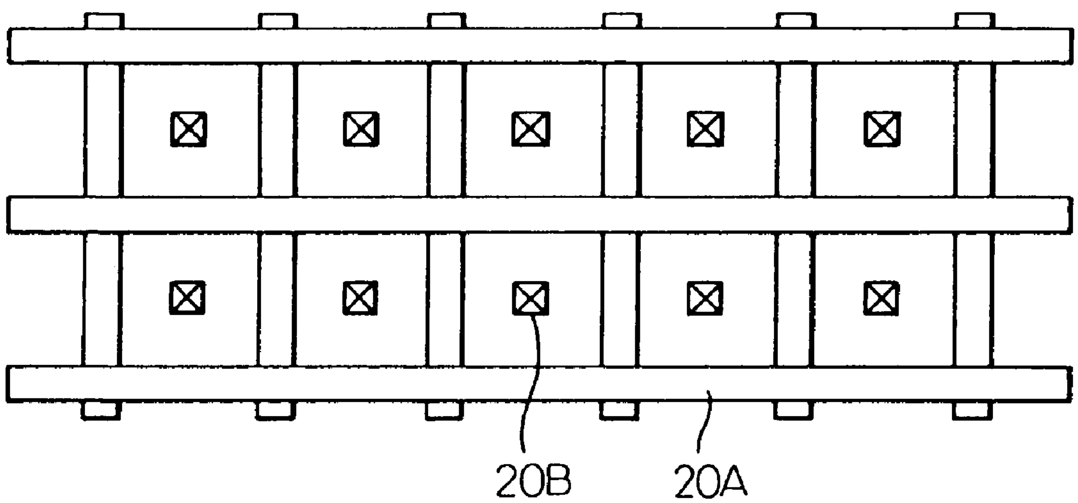


Fig.92A

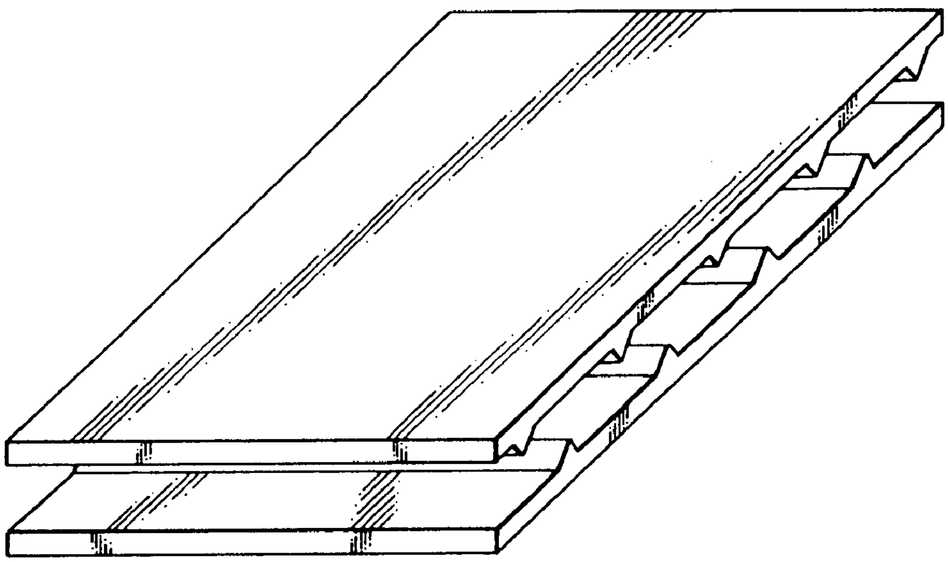


Fig.92B

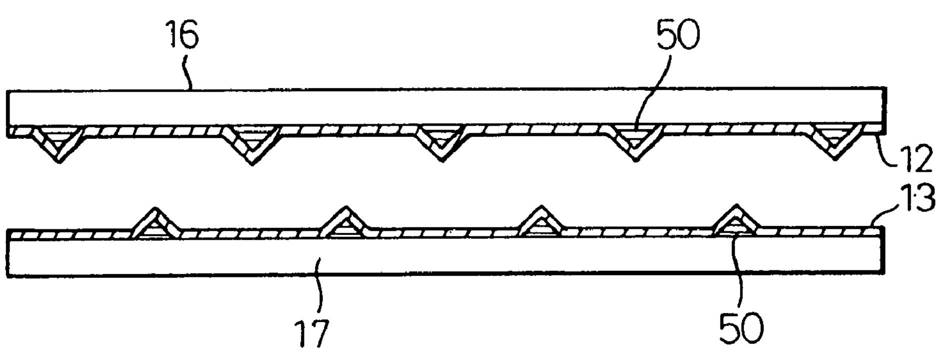


Fig.93

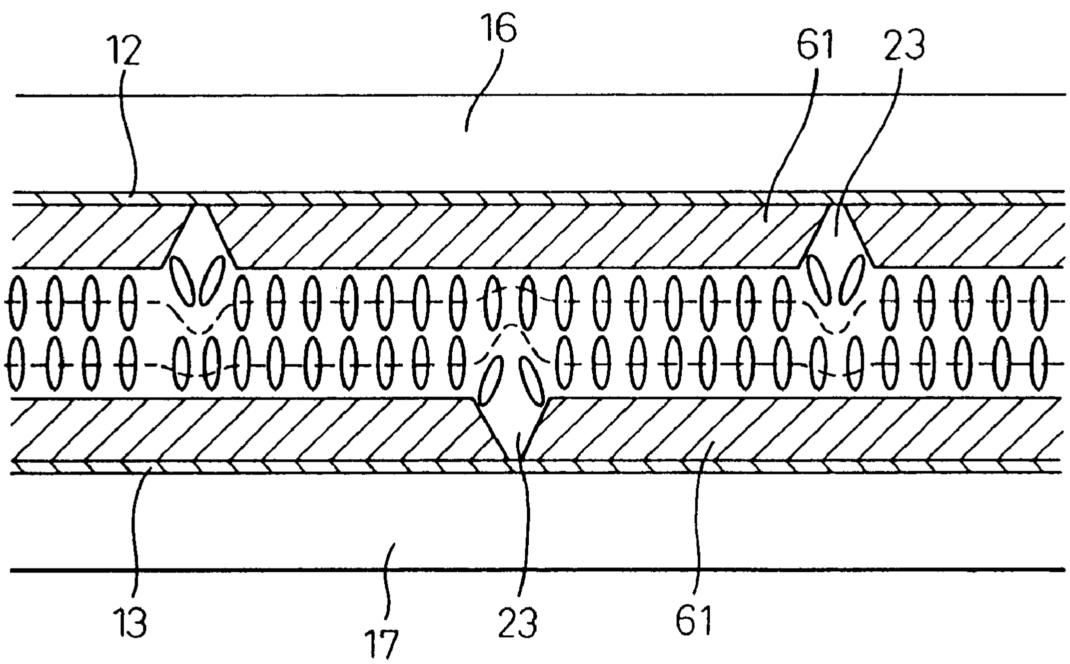


Fig.94

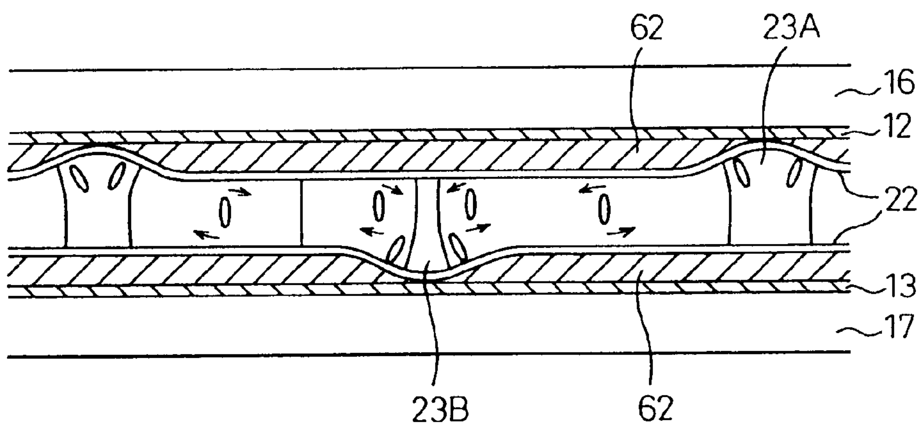


Fig.95

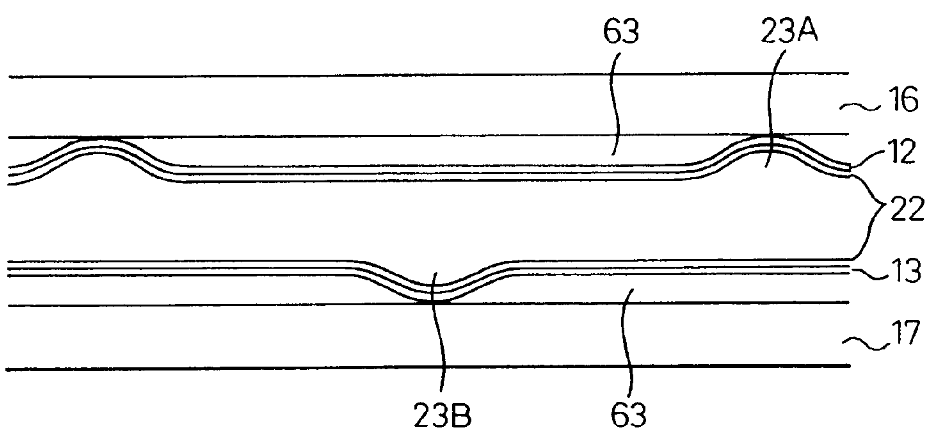


Fig.96

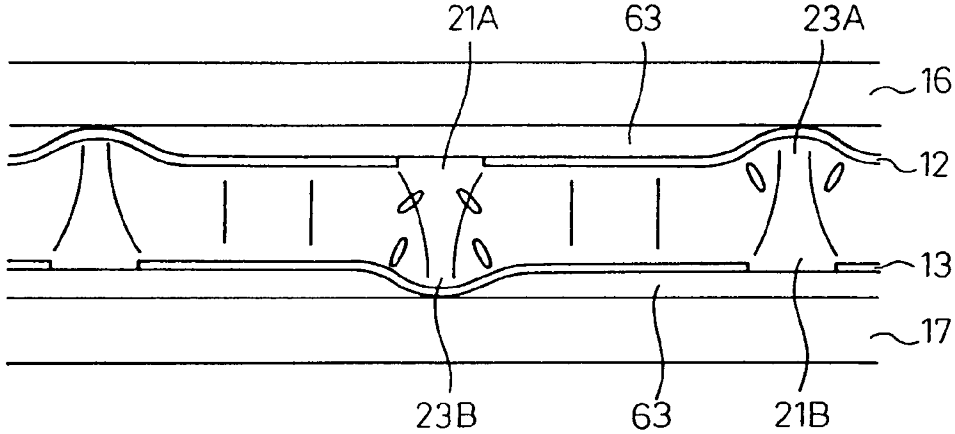


Fig.97

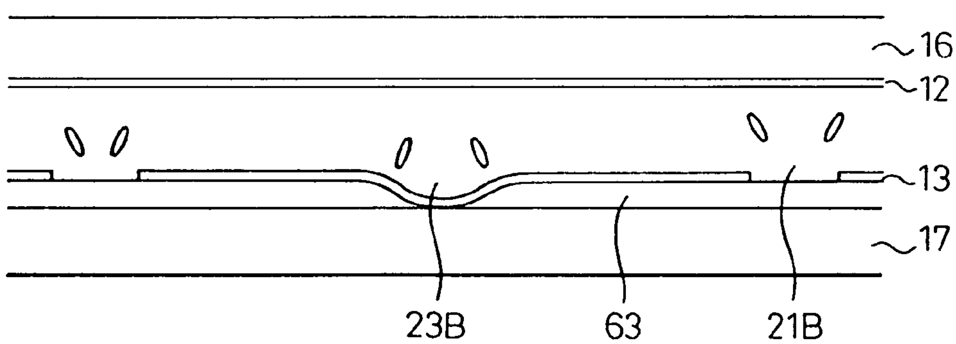


Fig.98

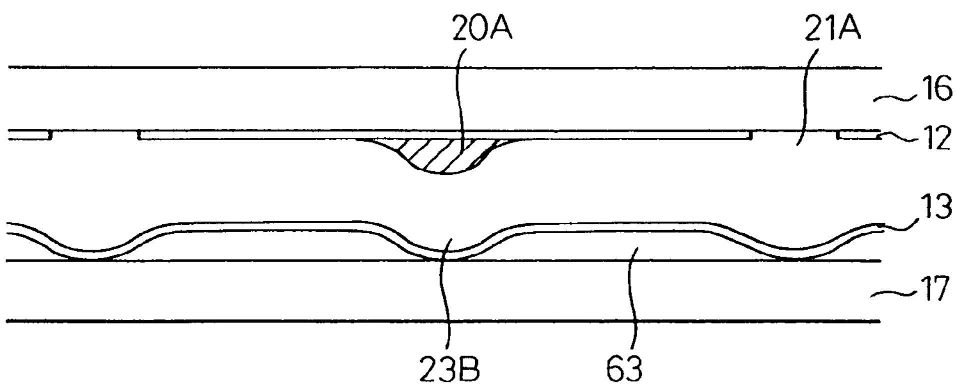


Fig.99A

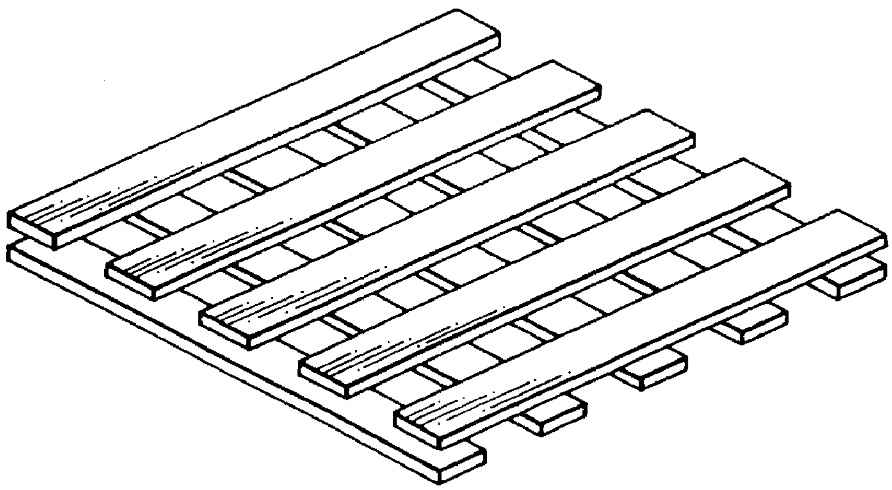


Fig.99B

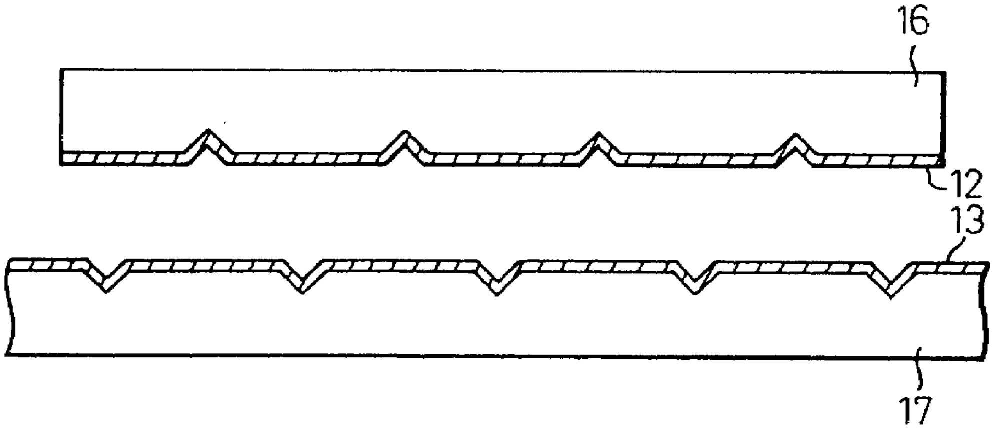


Fig.100A

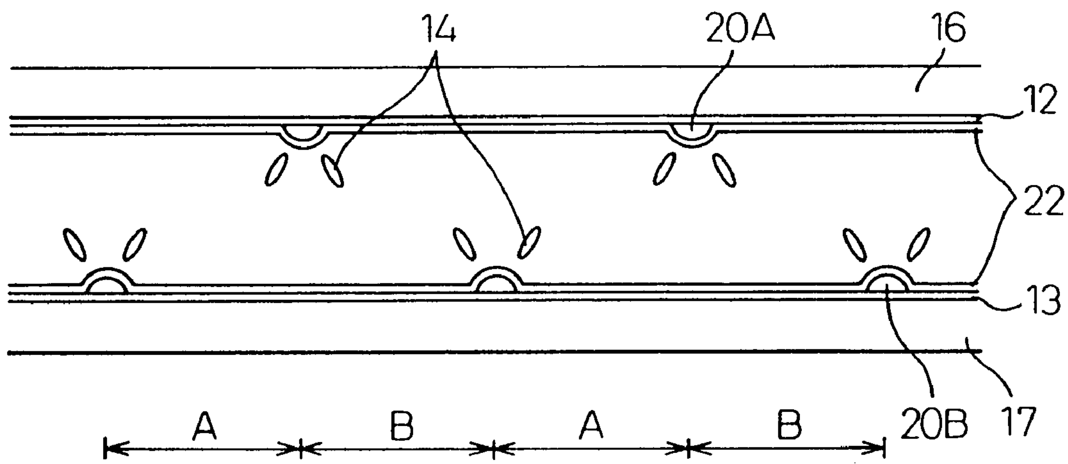


Fig.100B

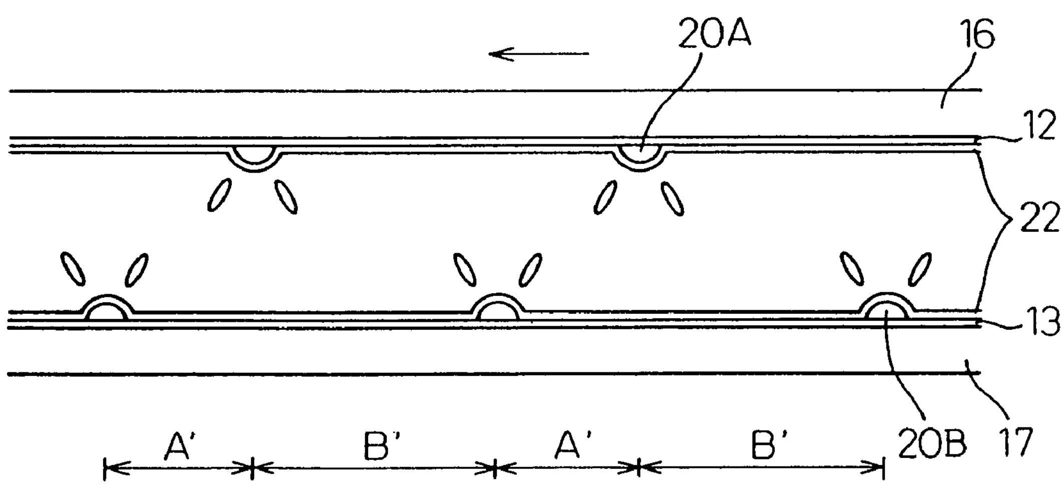


Fig.101A

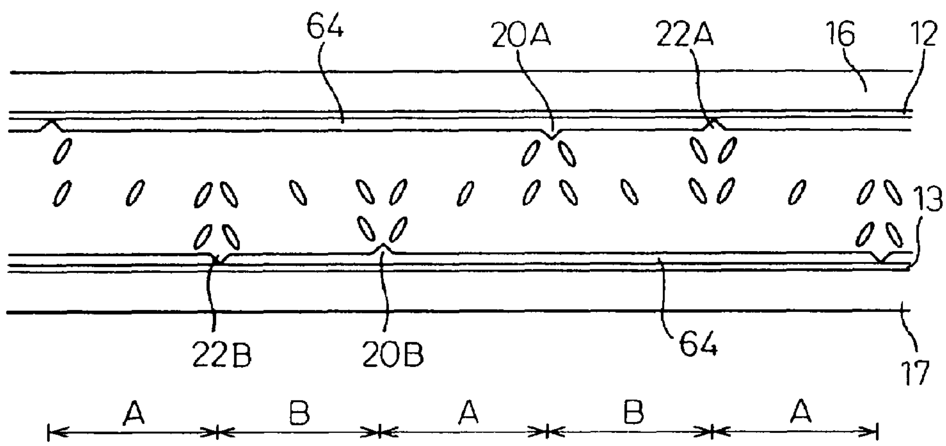


Fig.101B

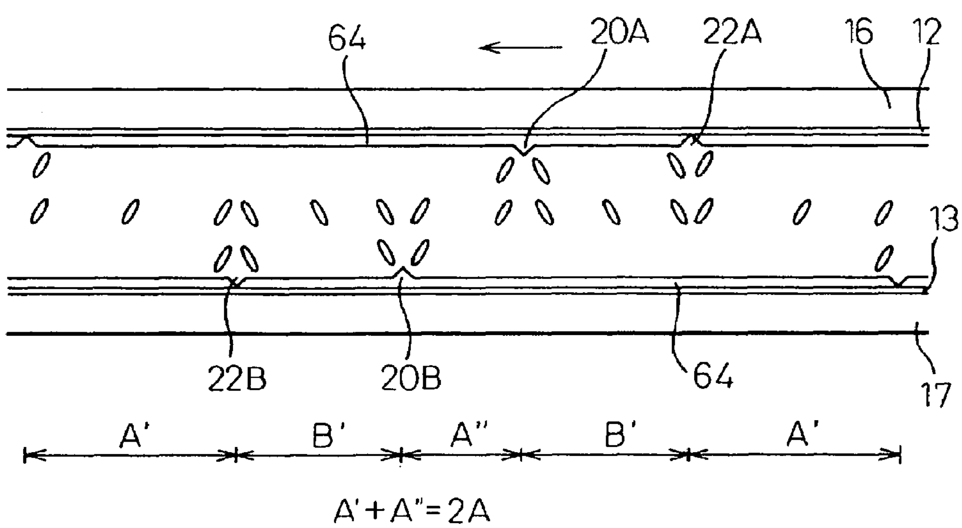


Fig.102

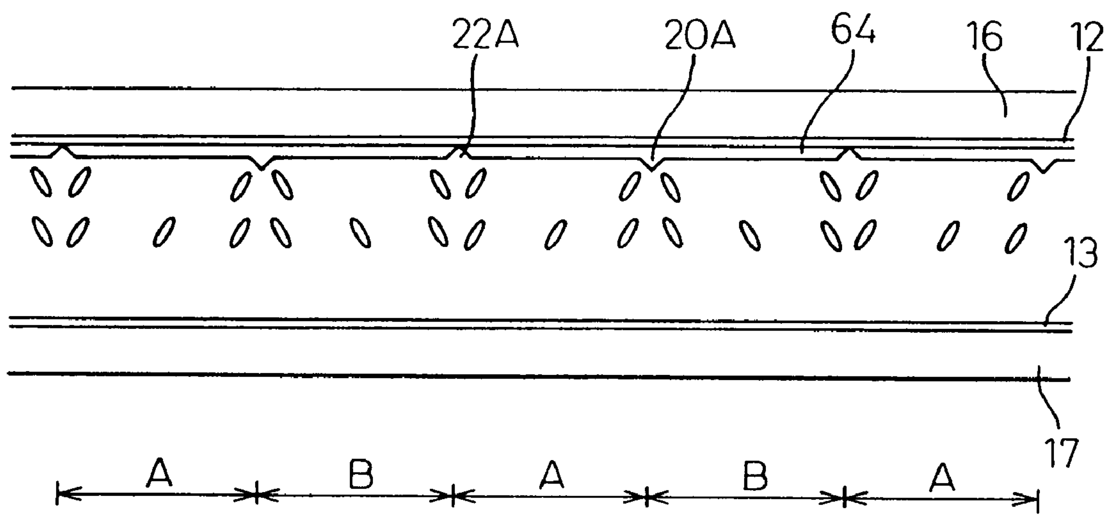


Fig.103A

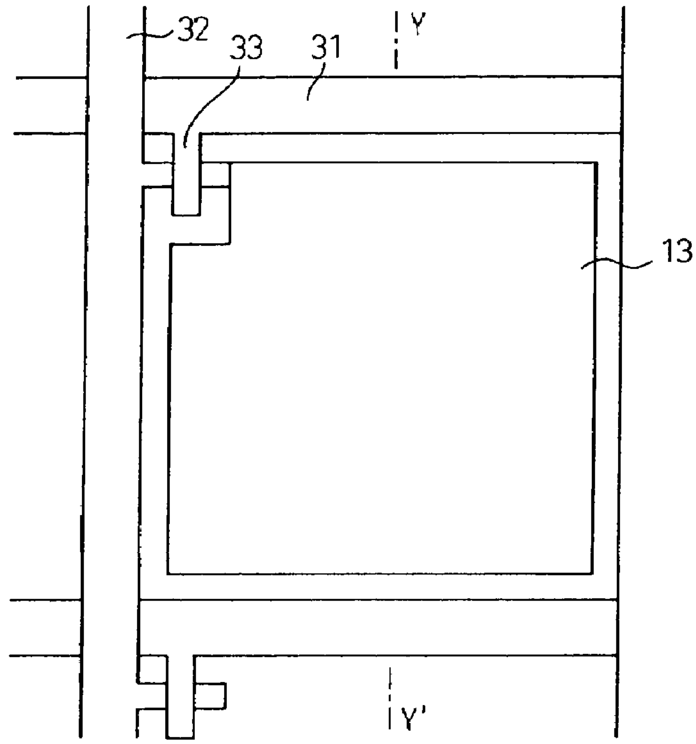


Fig.103B

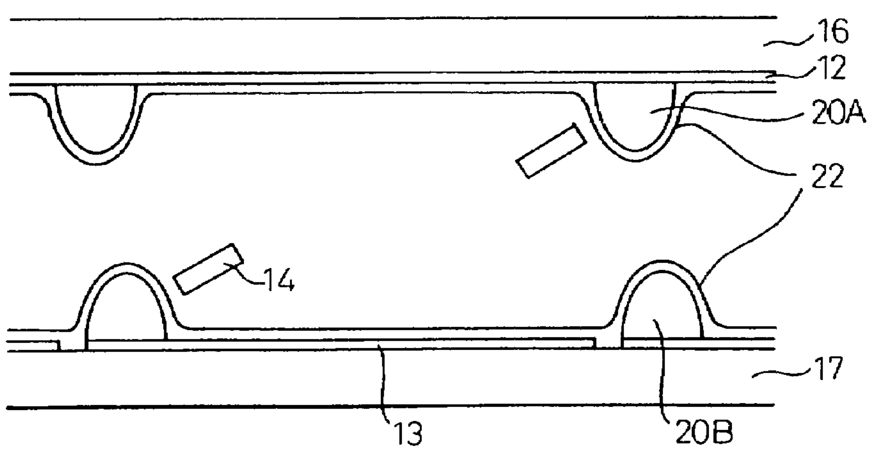


Fig.104

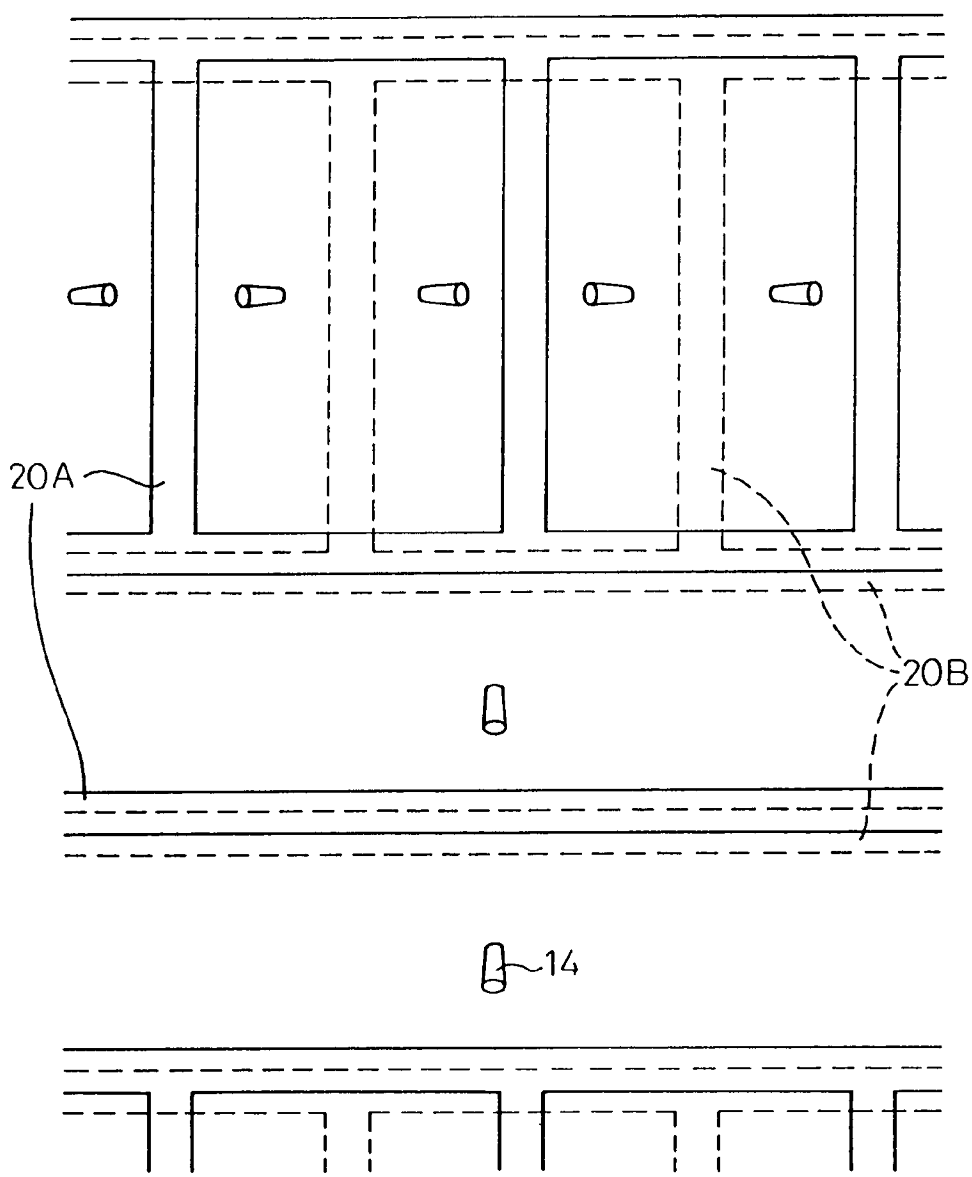


Fig.105A

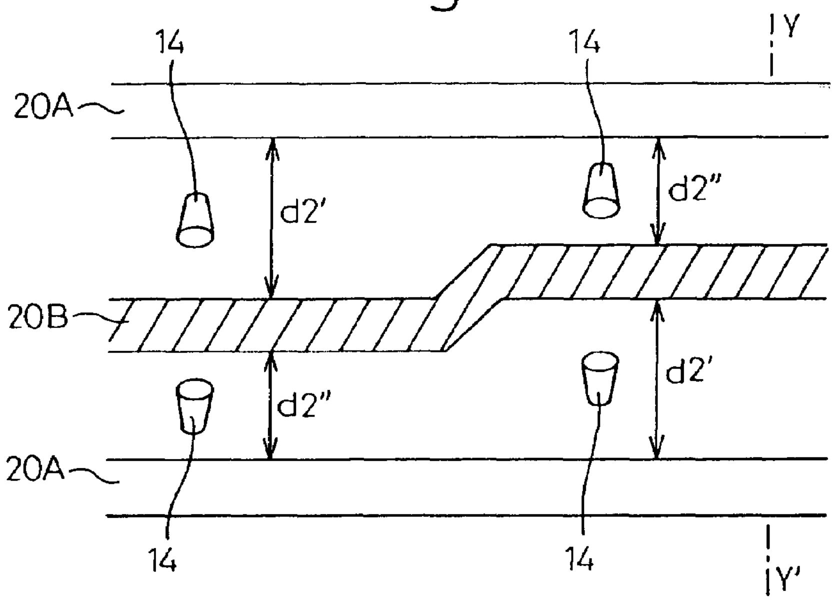


Fig.105B

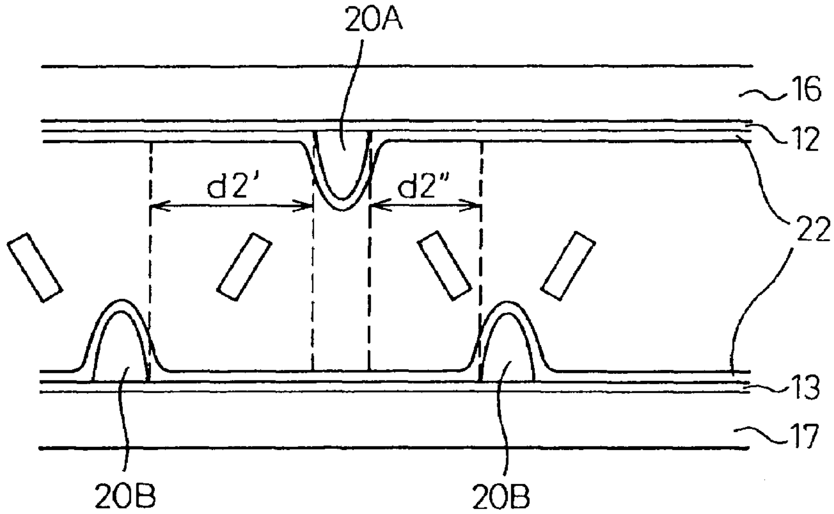


Fig.106

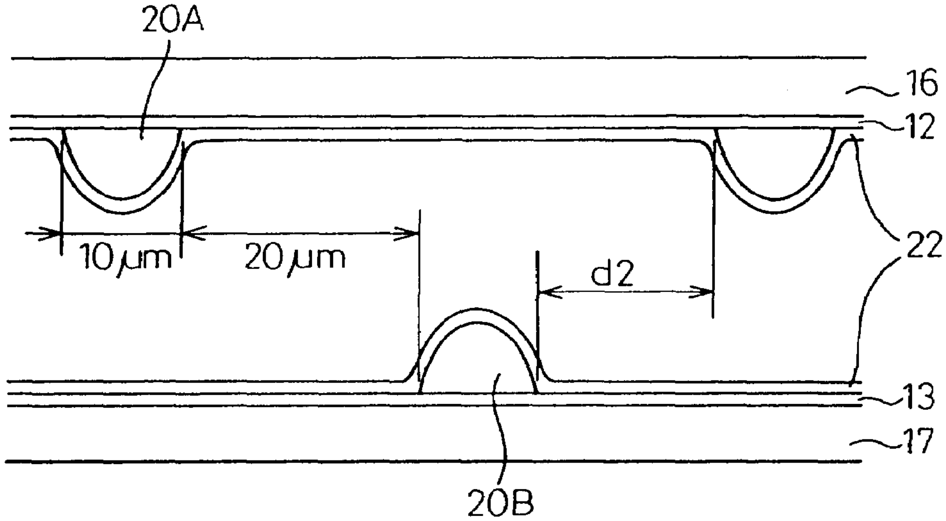


Fig.107

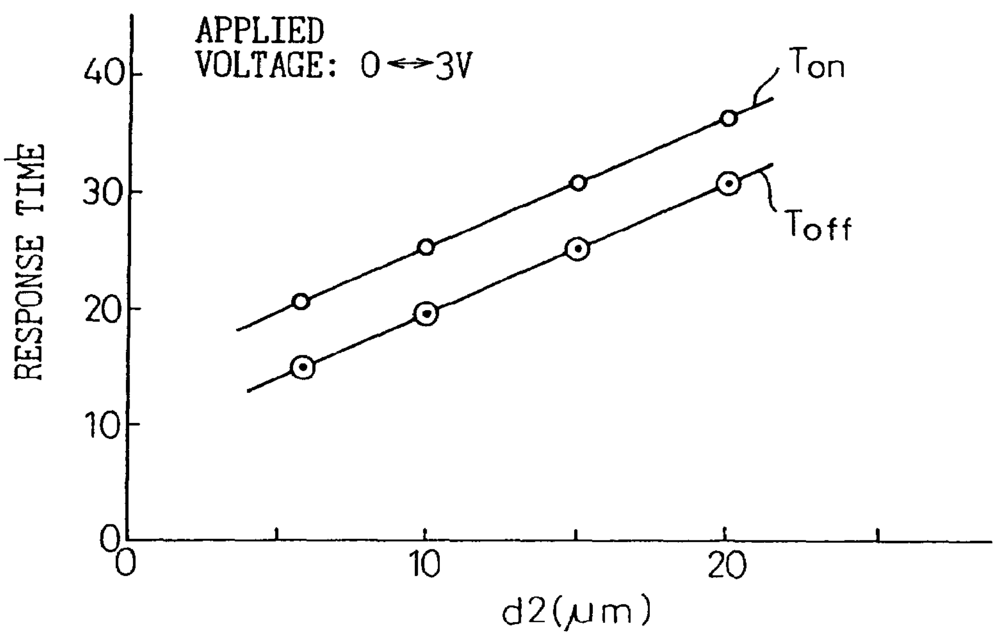


Fig.108A

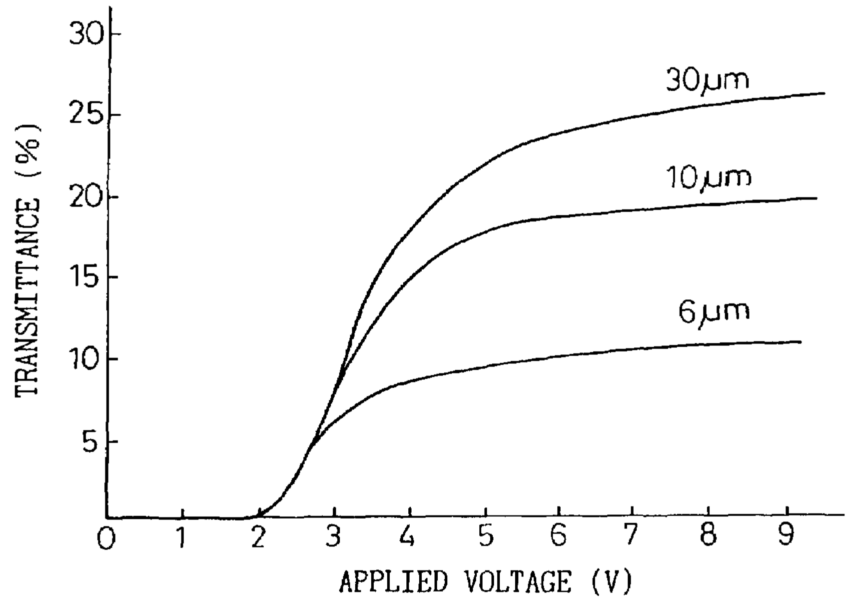


Fig.108B

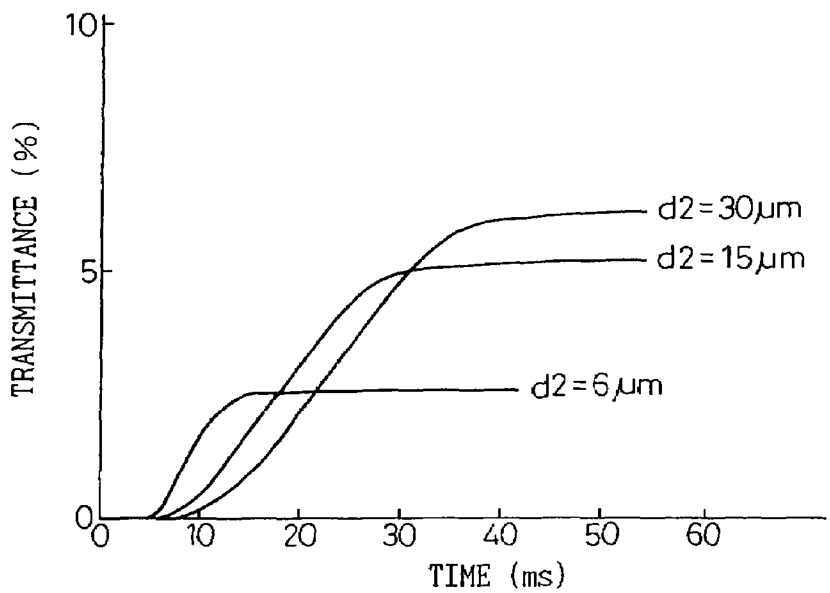


Fig.109A

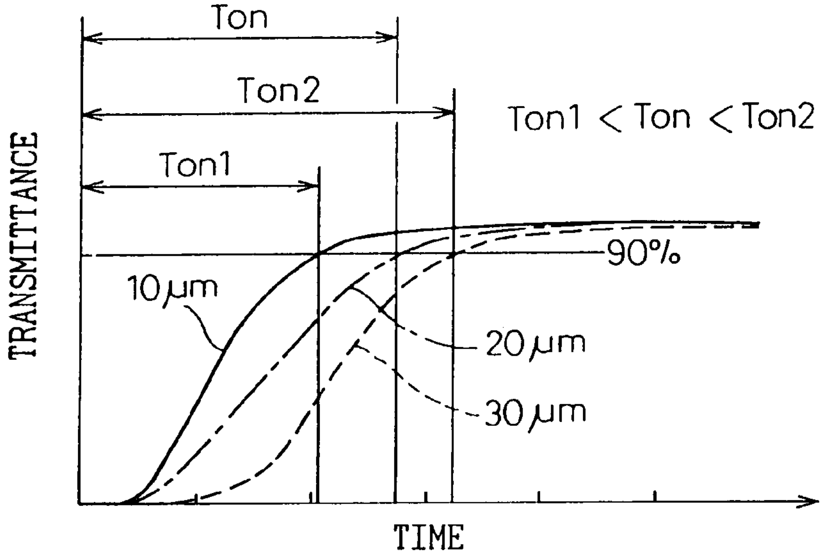


Fig.109B

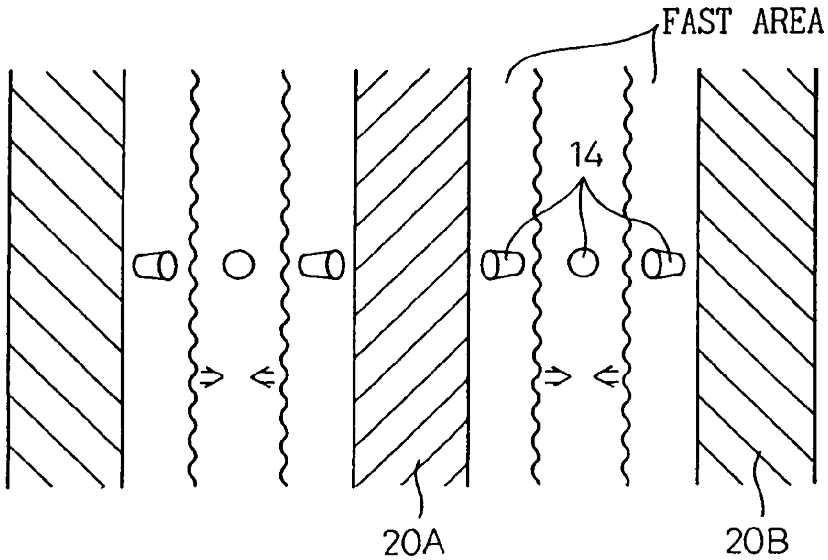


Fig.110

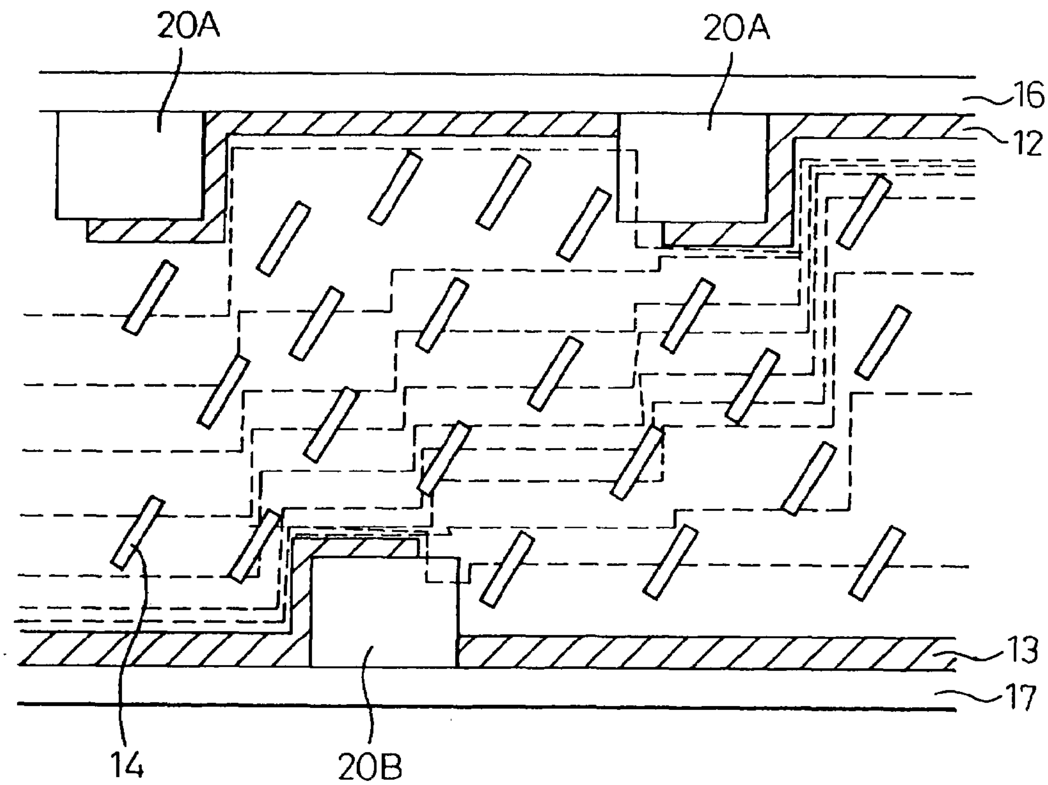


Fig. 111

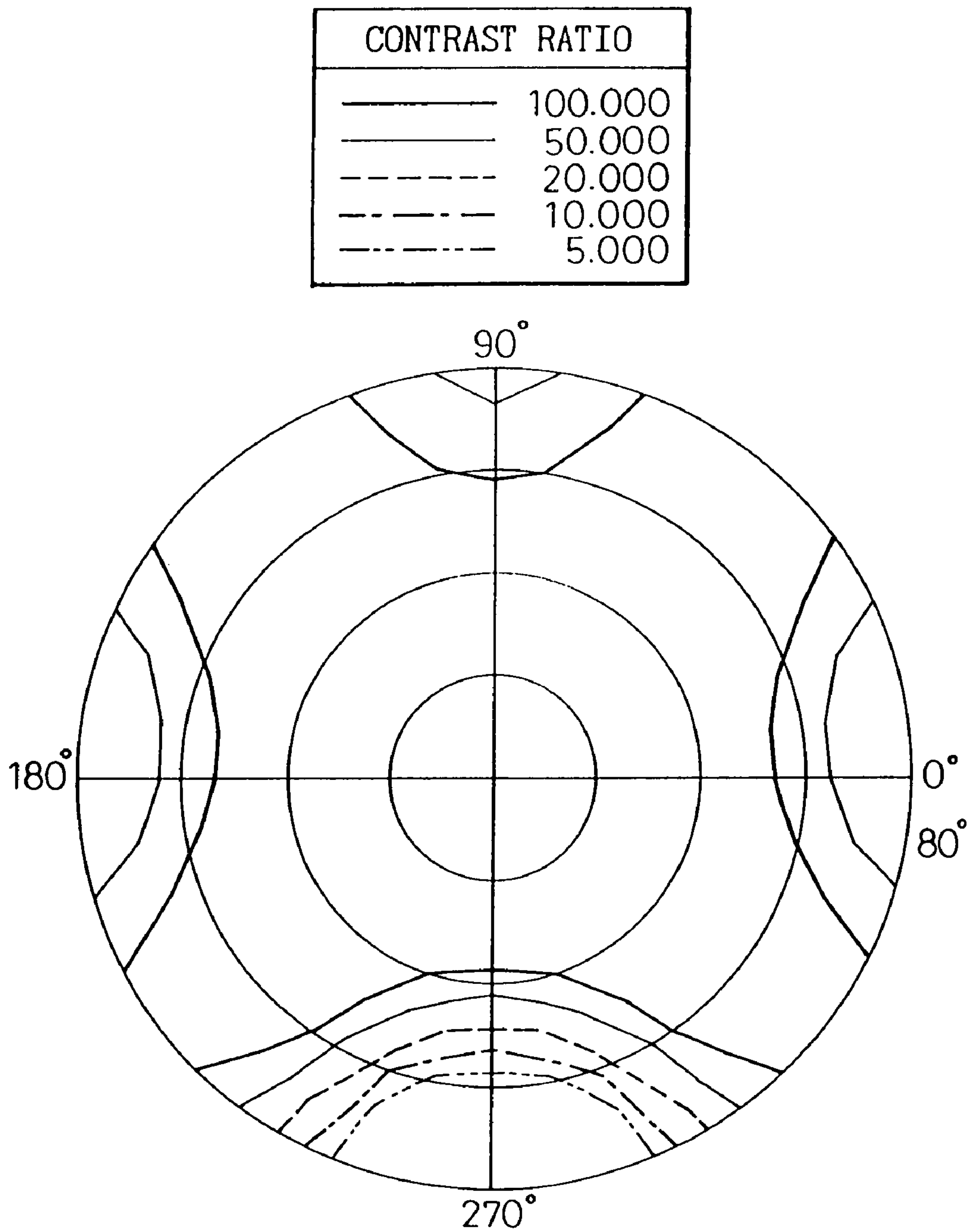


Fig.112

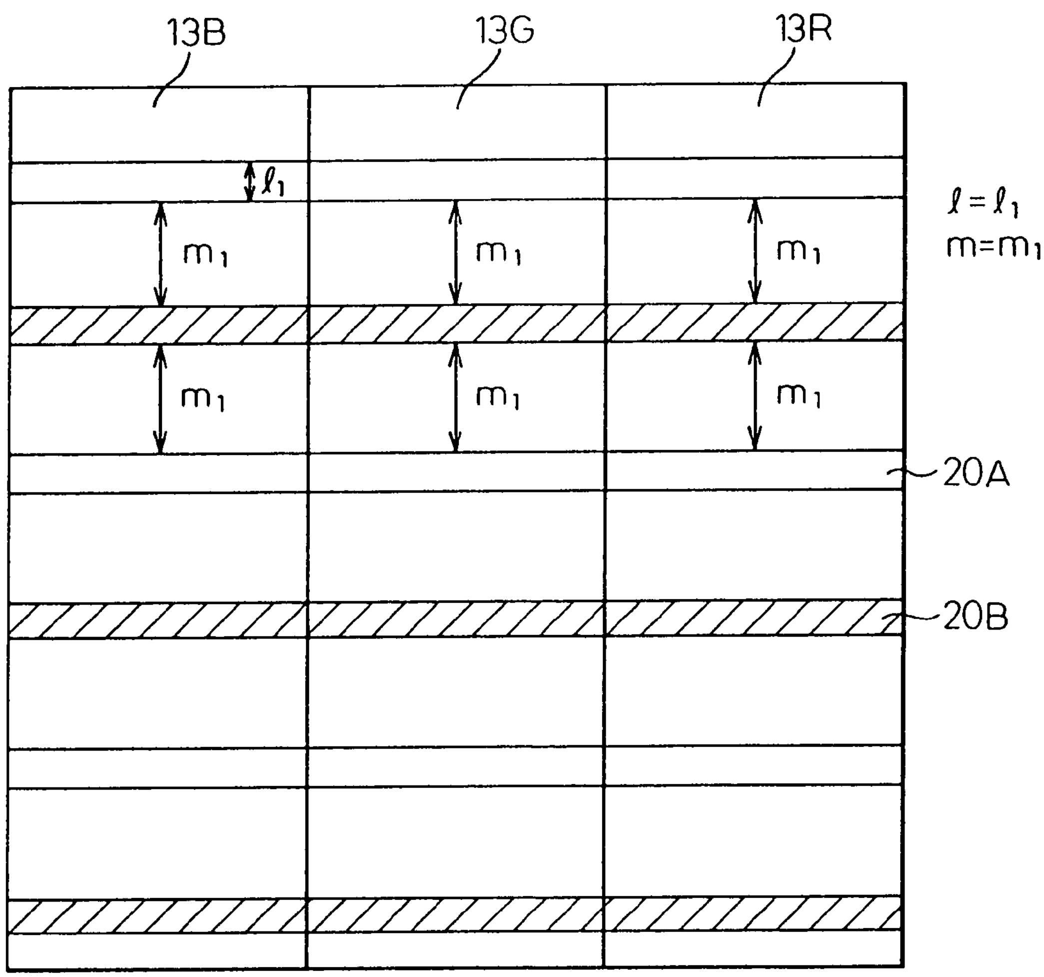


Fig.113

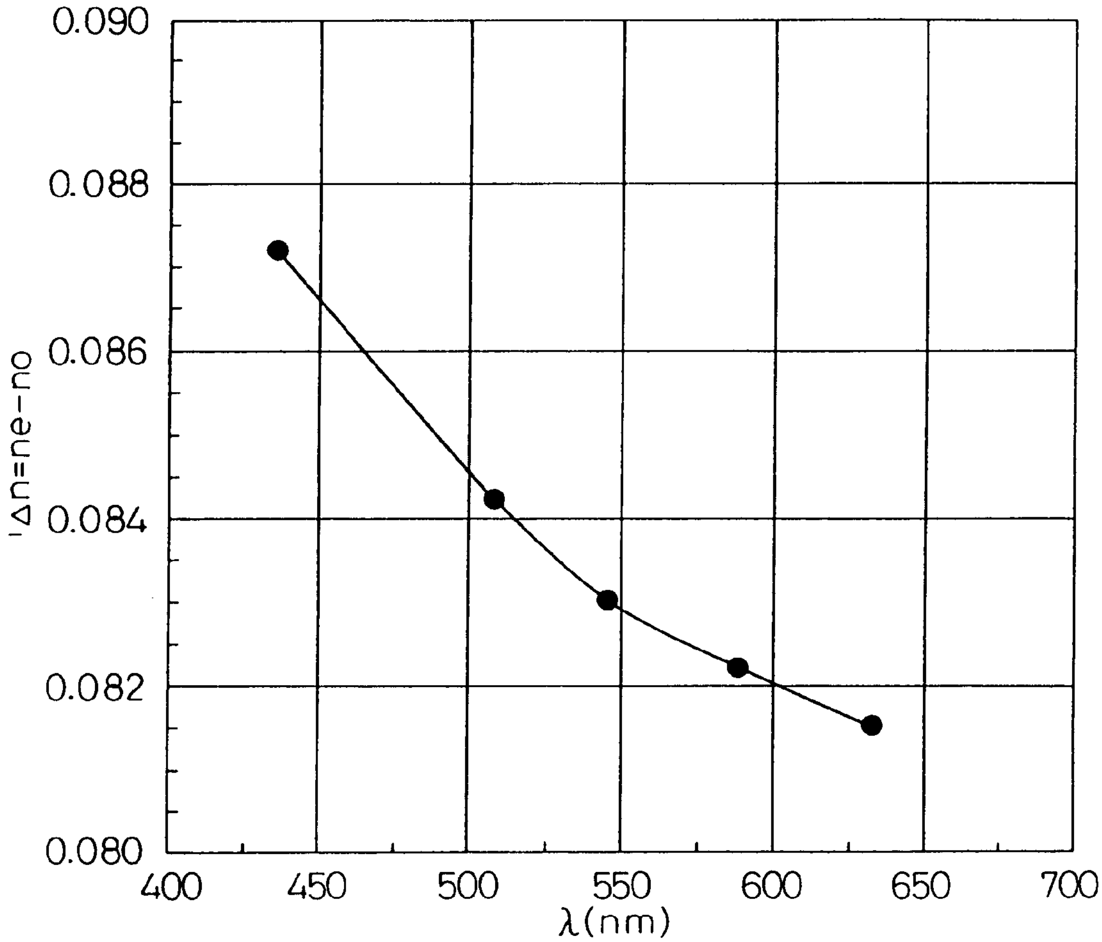

0.090
0.088
0.086
0.084
0.082
0.080
Δn=ne−no
400
450
500
550
600
650
700
λ(nm)

Fig.114

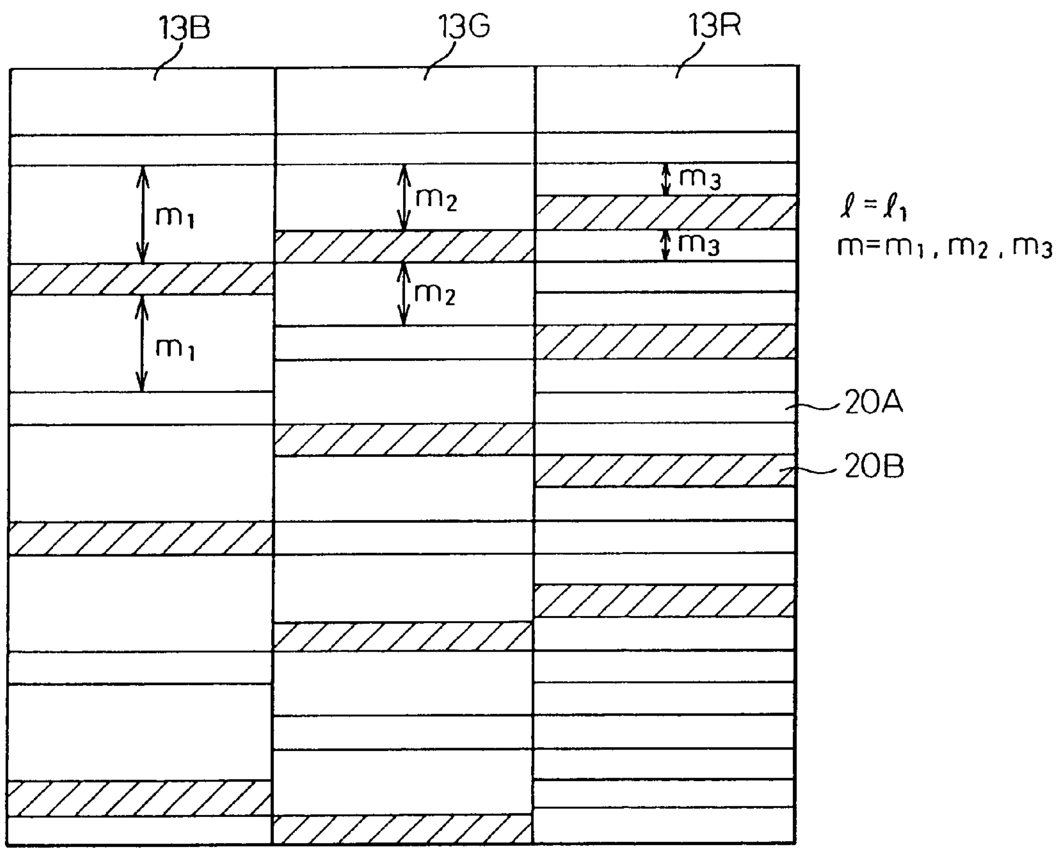


Fig.115

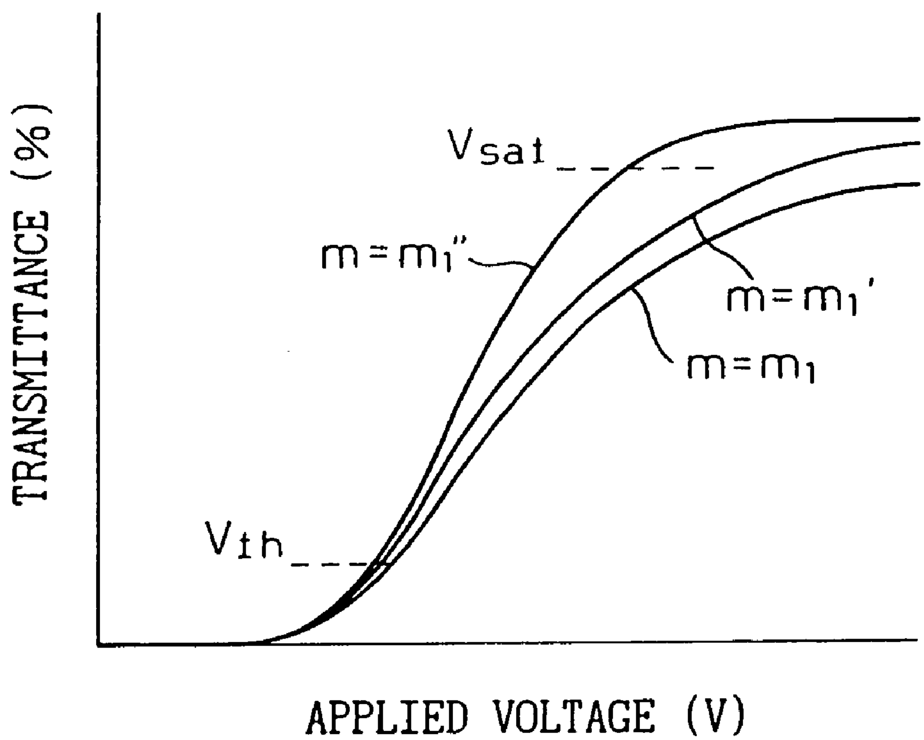
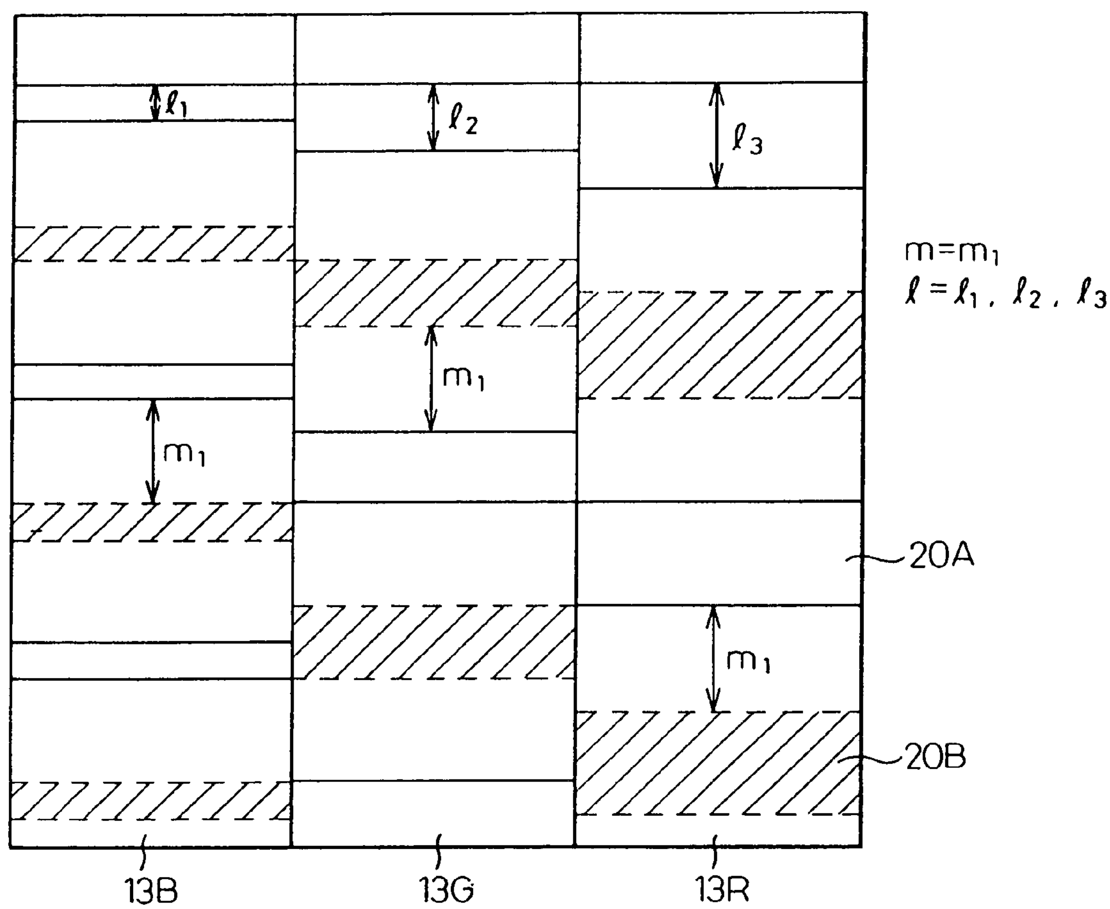


Fig.116



ℓ_1
ℓ_2
ℓ_3
$m = m_1$
$\ell = \ell_1, \ell_2, \ell_3$
m_1
m_1
m_1
20A
20B
13B
13G
13R

Fig.117

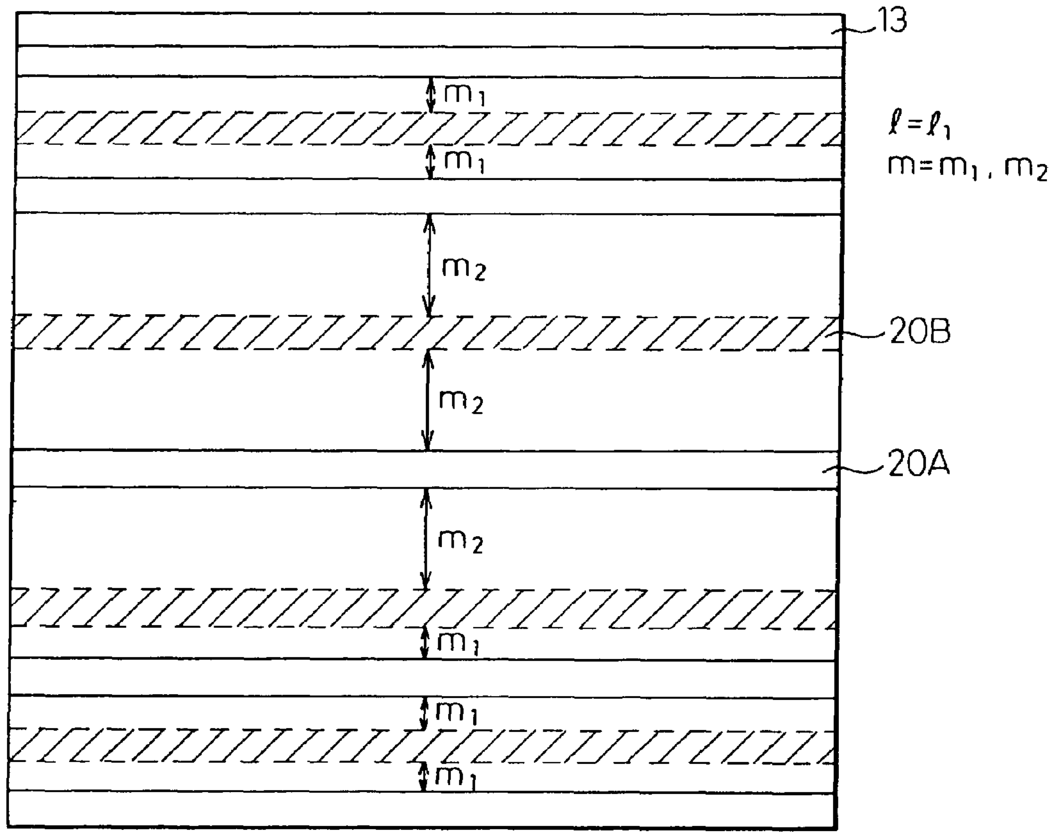


Fig.118

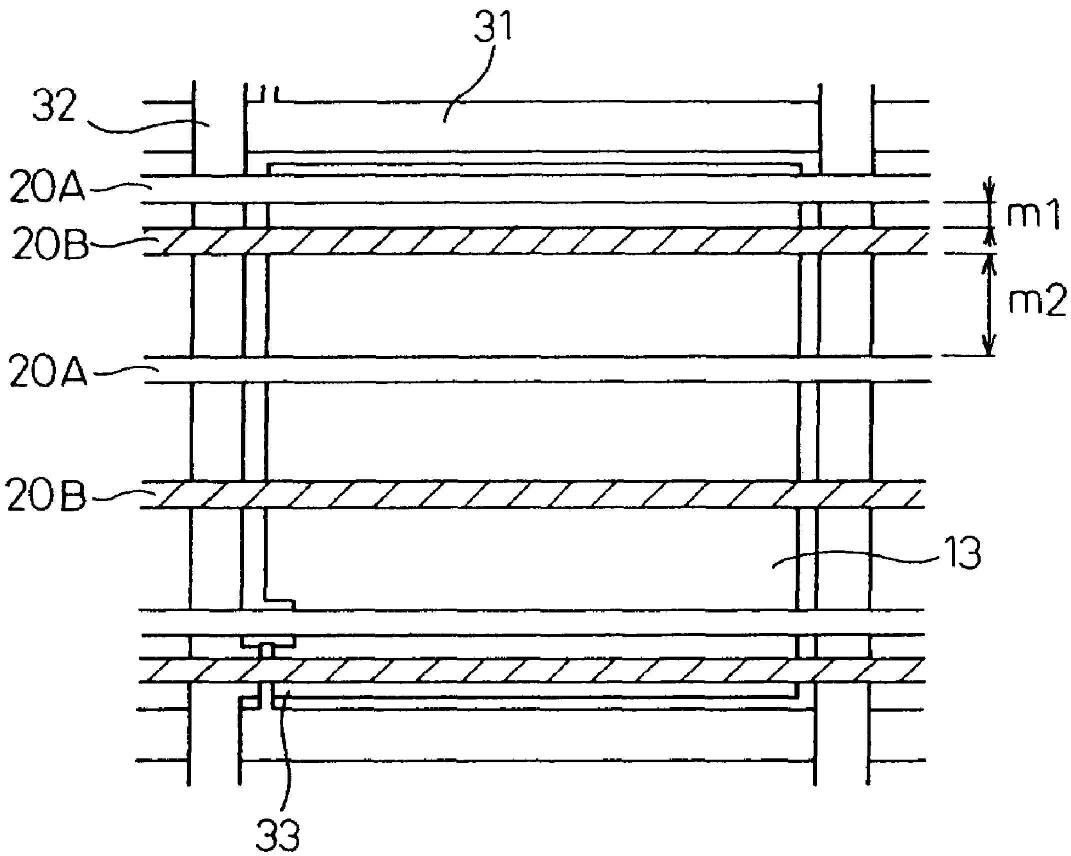


Fig.119

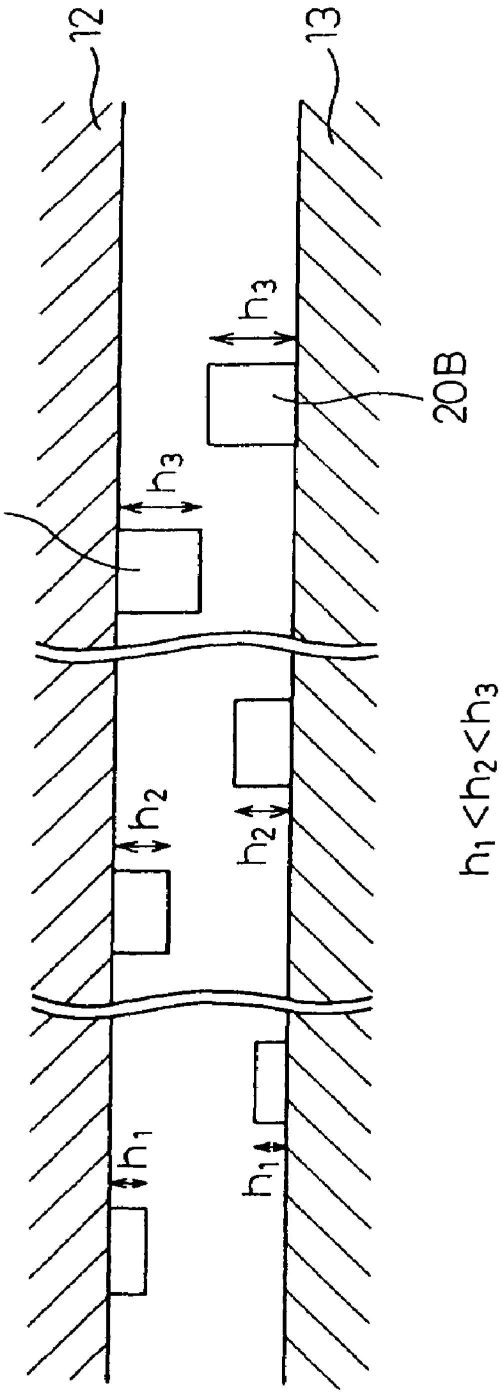


Fig.120

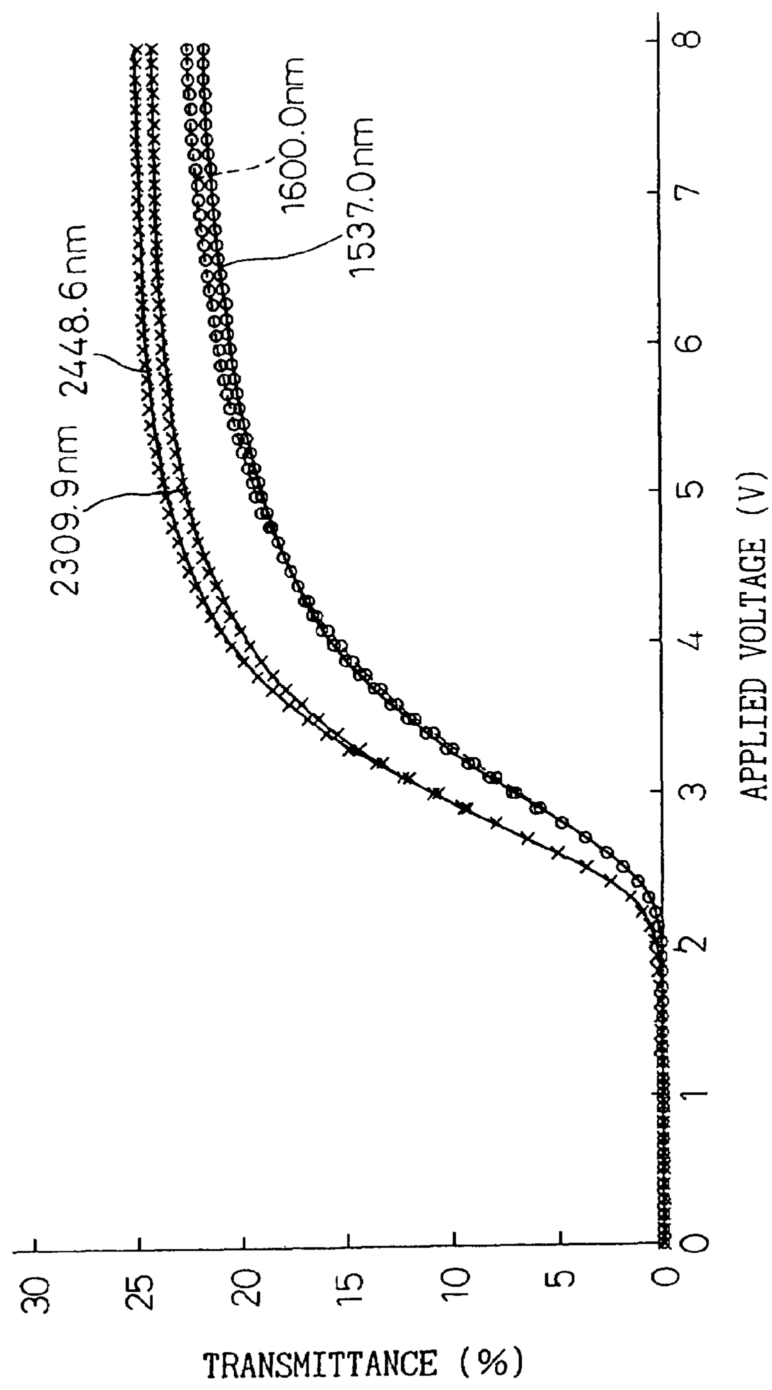

2309.9nm
2448.6nm
1600.0nm
1537.0nm
TRANSMITTANCE (%)
APPLIED VOLTAGE (V)
0
5
10
15
20
25
30
0
1
2
3
4
5
6
7
8

Fig.121

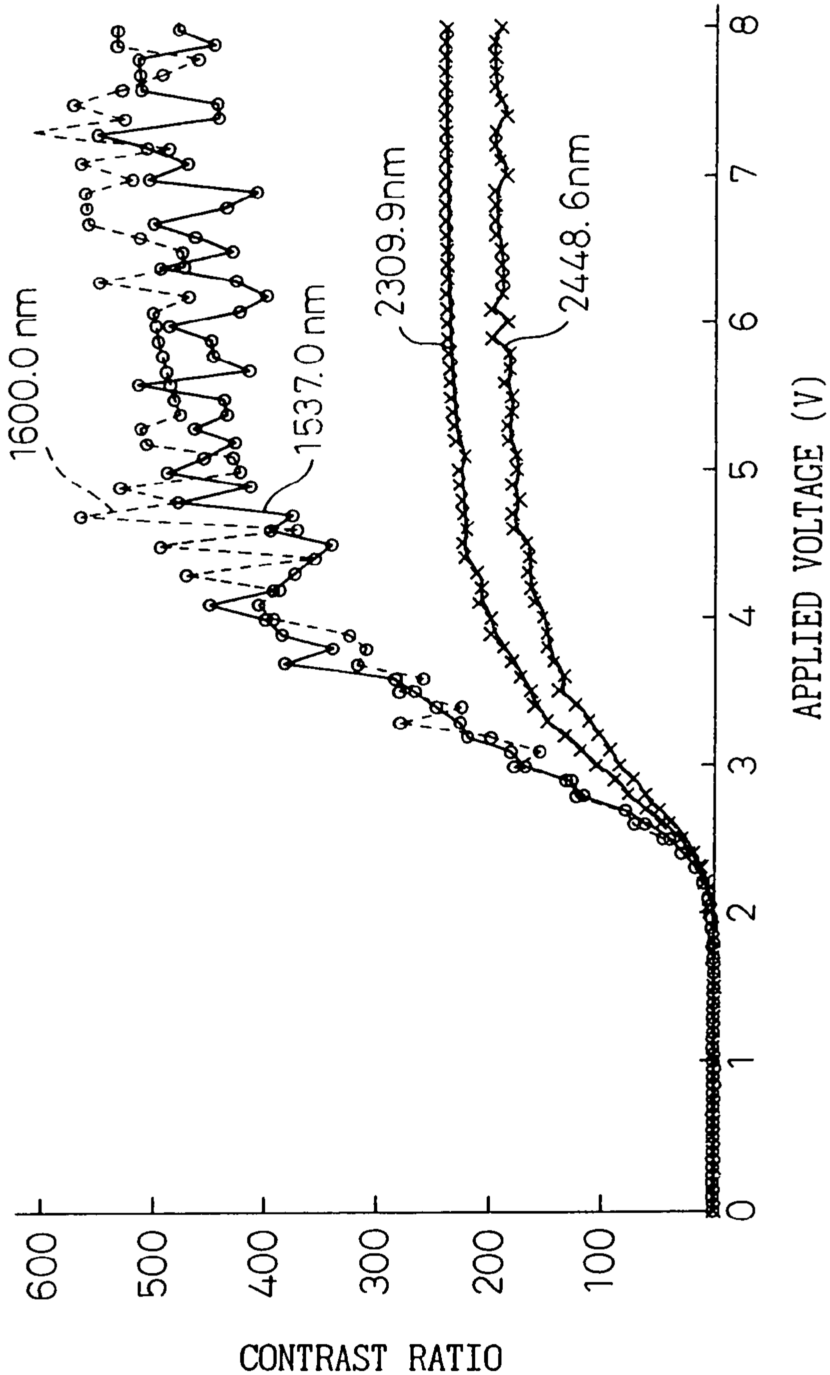

1600.0 nm
1537.0 nm
2309.9nm
2448.6nm
600
500
400
300
200
100
CONTRAST RATIO
0
1
2
3
4
5
6
7
8
APPLIED VOLTAGE (V)

Fig.122

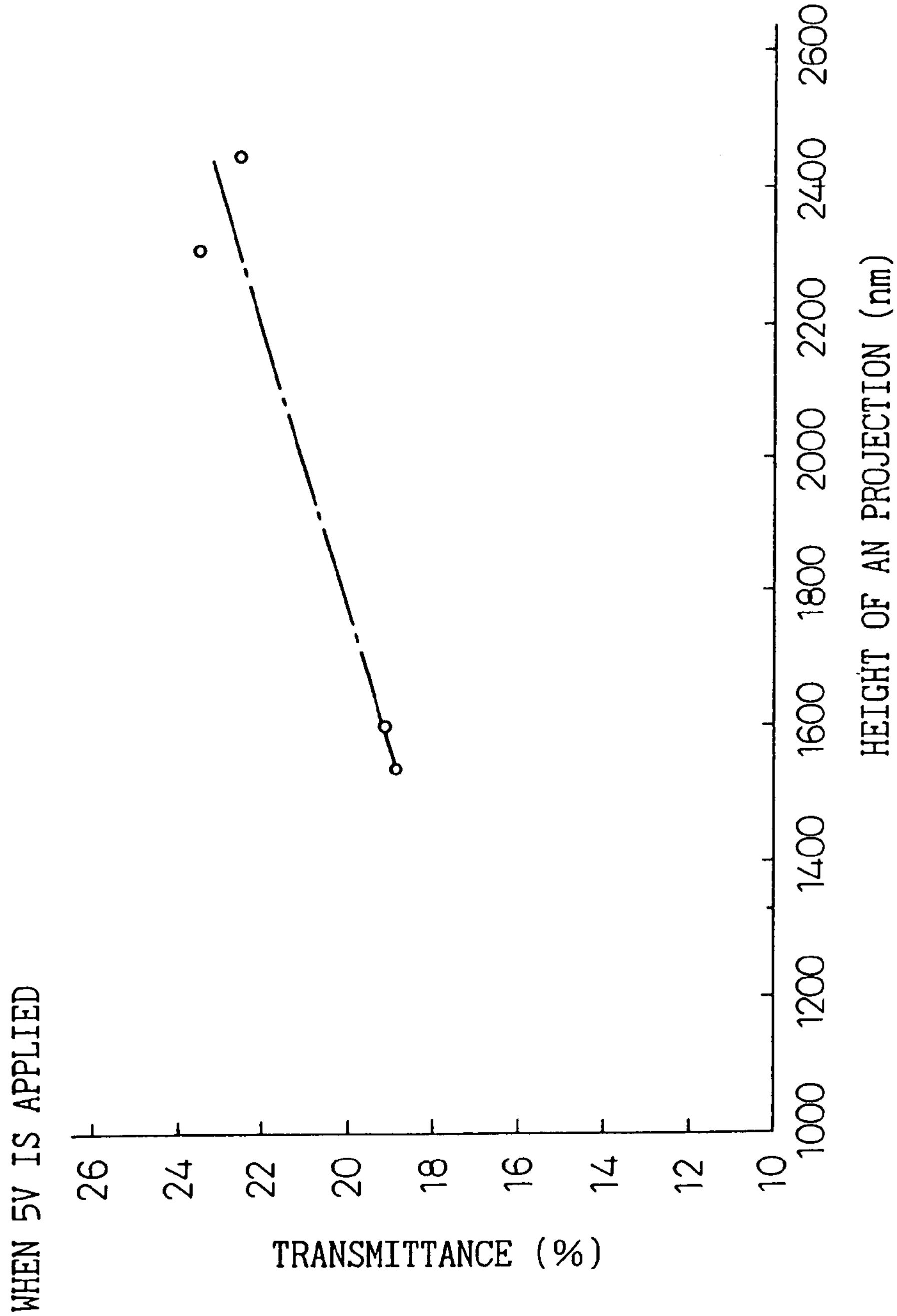
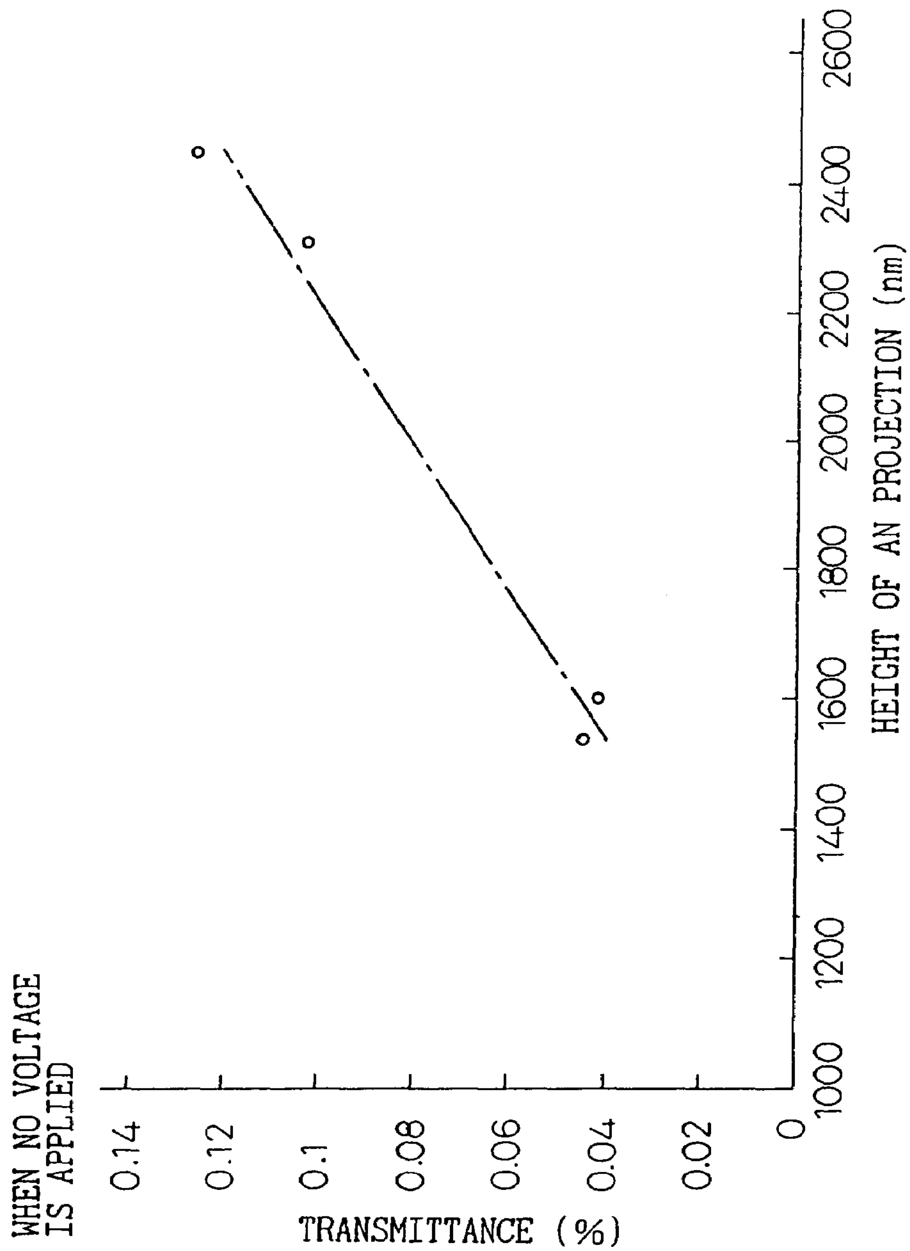

WHEN 5V IS APPLIED
TRANSMITTANCE (%)
26
24
22
20
18
16
14
12
10
1000
1200
1400
1600
1800
2000
2200
2400
2600
HEIGHT OF AN PROJECTION (nm)

Fig.123


WHEN NO VOLTAGE IS APPLIED
TRANSMITTANCE (%)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1000
1200
1400
1600
1800
2000
2200
2400
2600
HEIGHT OF AN PROJECTION (nm)

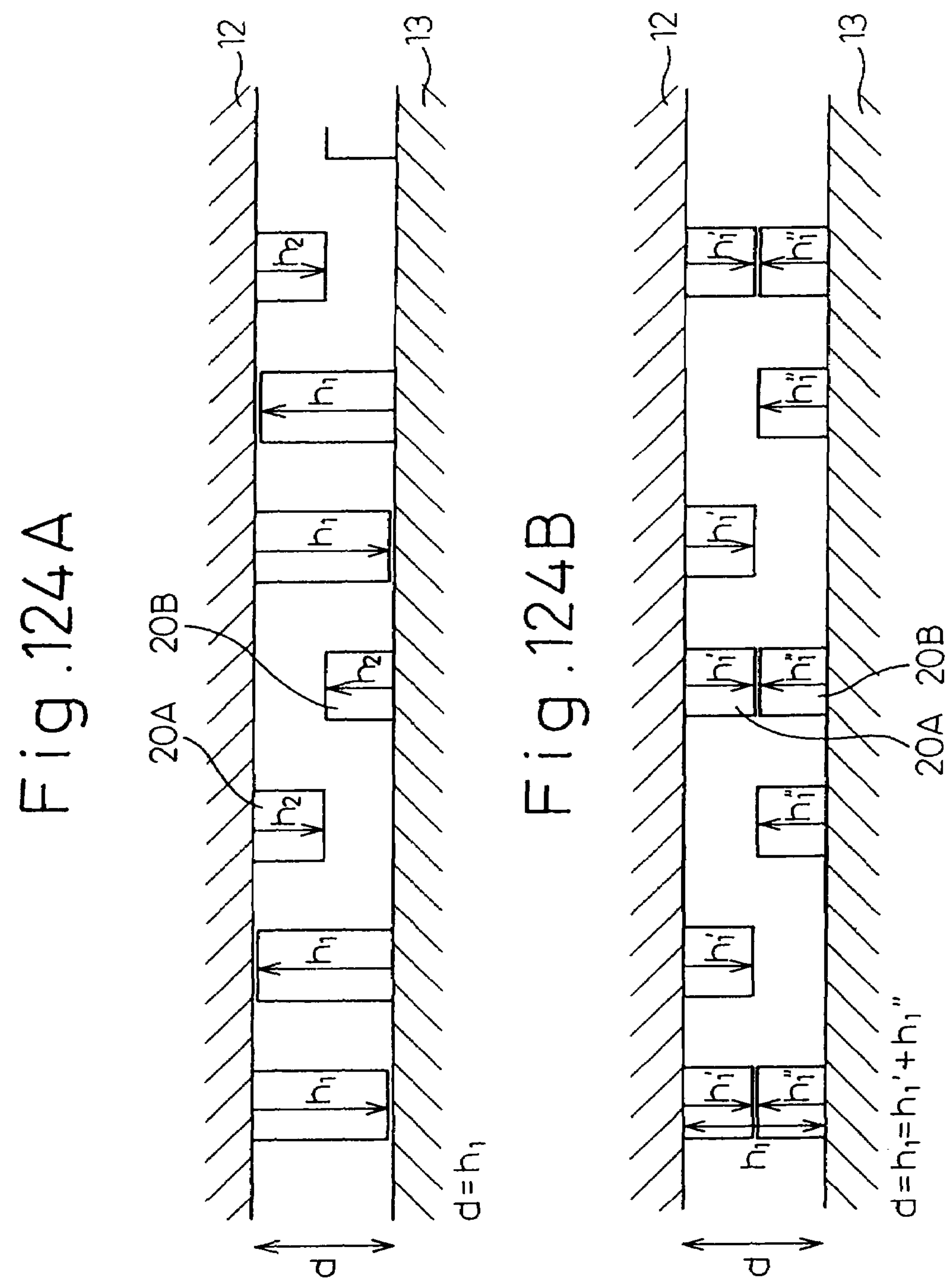


Fig.124A

Fig.124B

Fig.125A

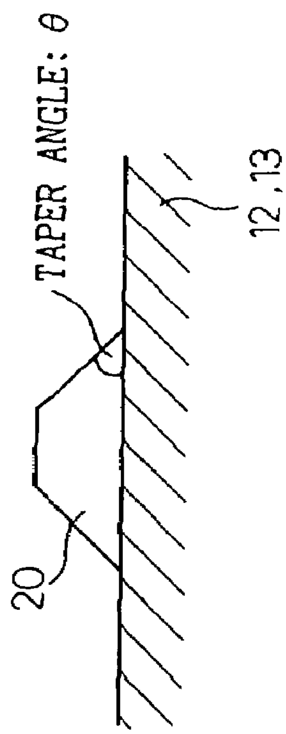


Fig.125B

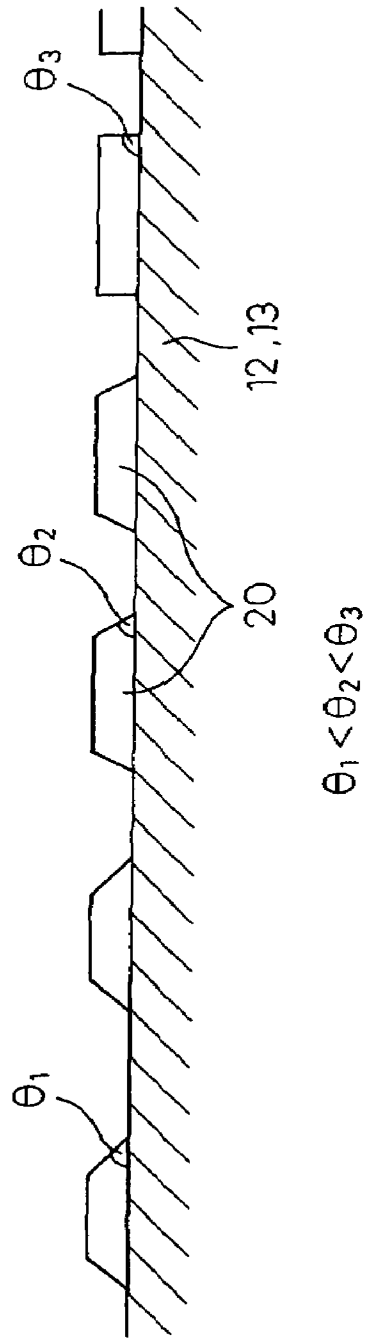


Fig. 126

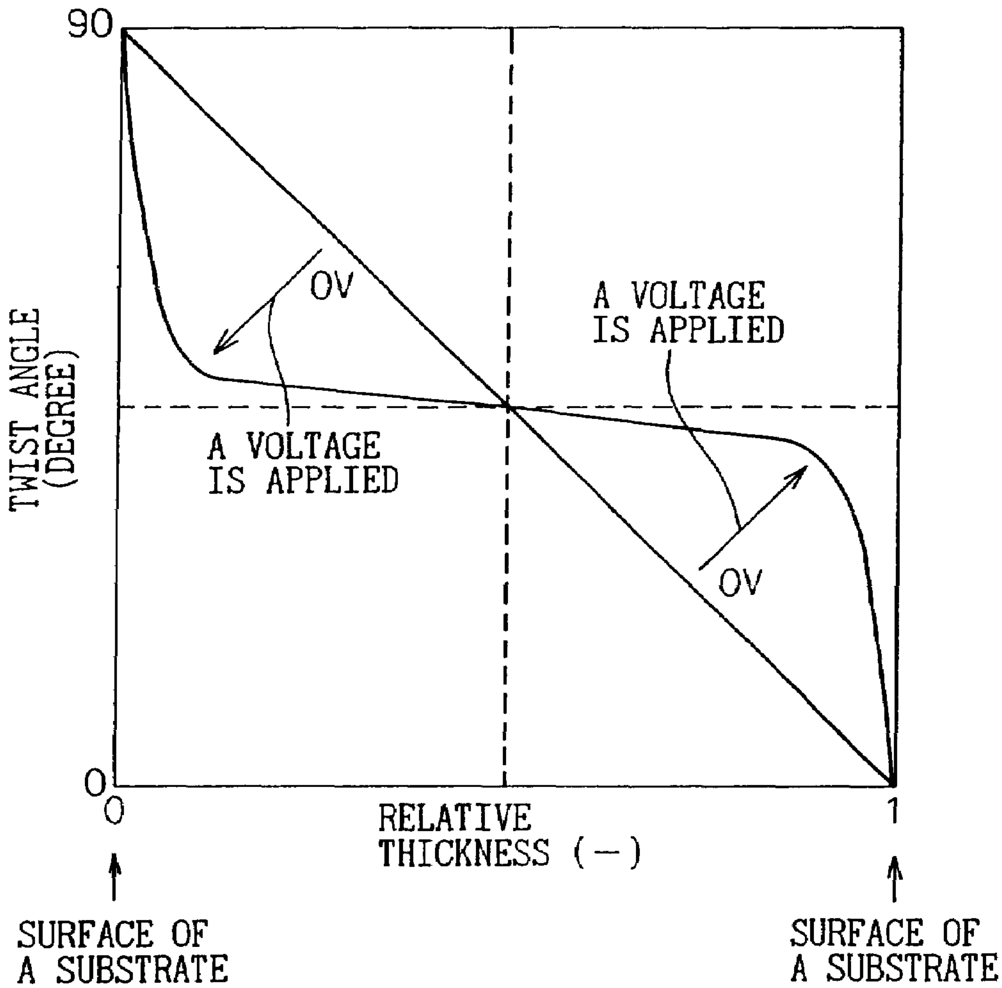

90
0
TWIST ANGLE
(DEGREE)
0V
A VOLTAGE
IS APPLIED
A VOLTAGE
IS APPLIED
0V
0
1
RELATIVE
THICKNESS (−)
SURFACE OF
A SUBSTRATE
SURFACE OF
A SUBSTRATE

Fig. 127

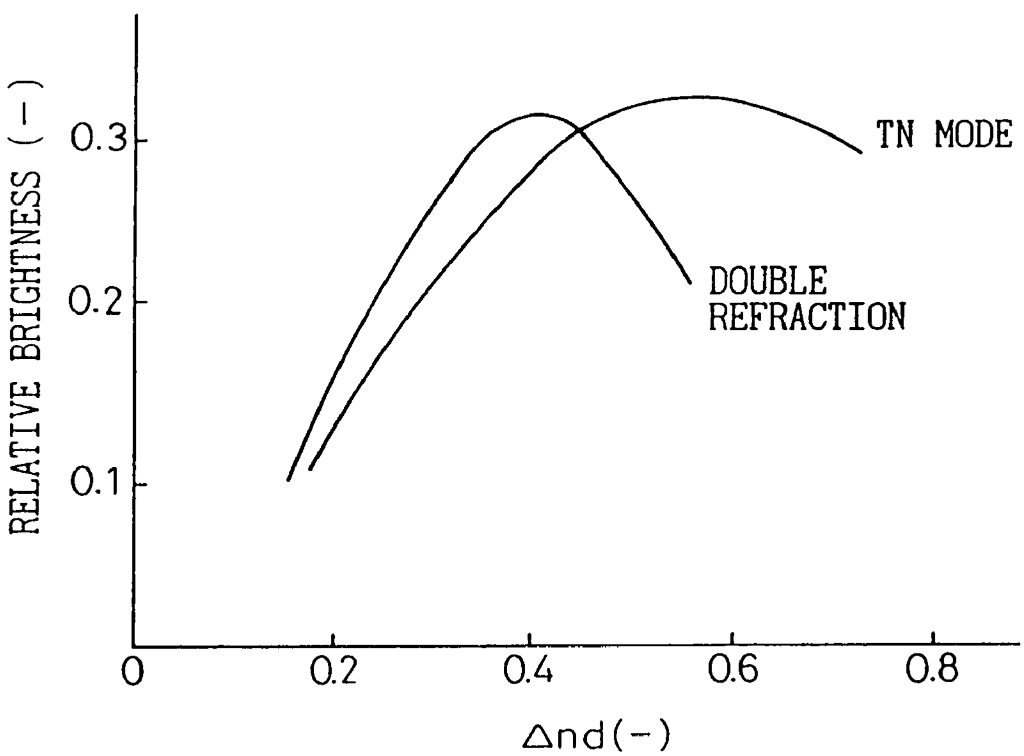
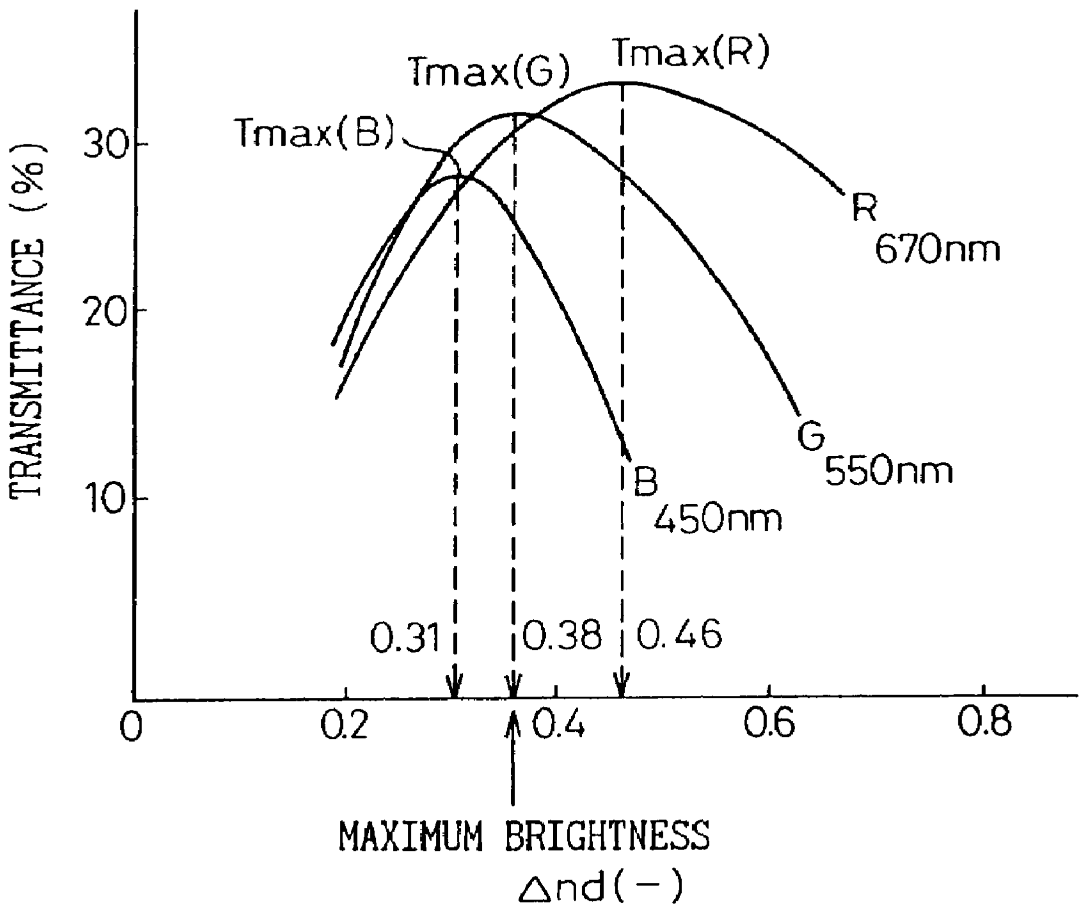

RELATIVE BRIGHTNESS (−)
0.3
0.2
0.1
0
0.2
0.4
0.6
0.8
Δnd(−)
TN MODE
DOUBLE
REFRACTION

Fig.128



TRANSMITTANCE (%)
30
20
10
Tmax(B)
Tmax(G)
Tmax(R)
R
670nm
G
550nm
B
450nm
0.31
0.38
0.46
0
0.2
0.4
0.6
0.8
MAXIMUM BRIGHTNESS
Δnd(−)

Fig.129

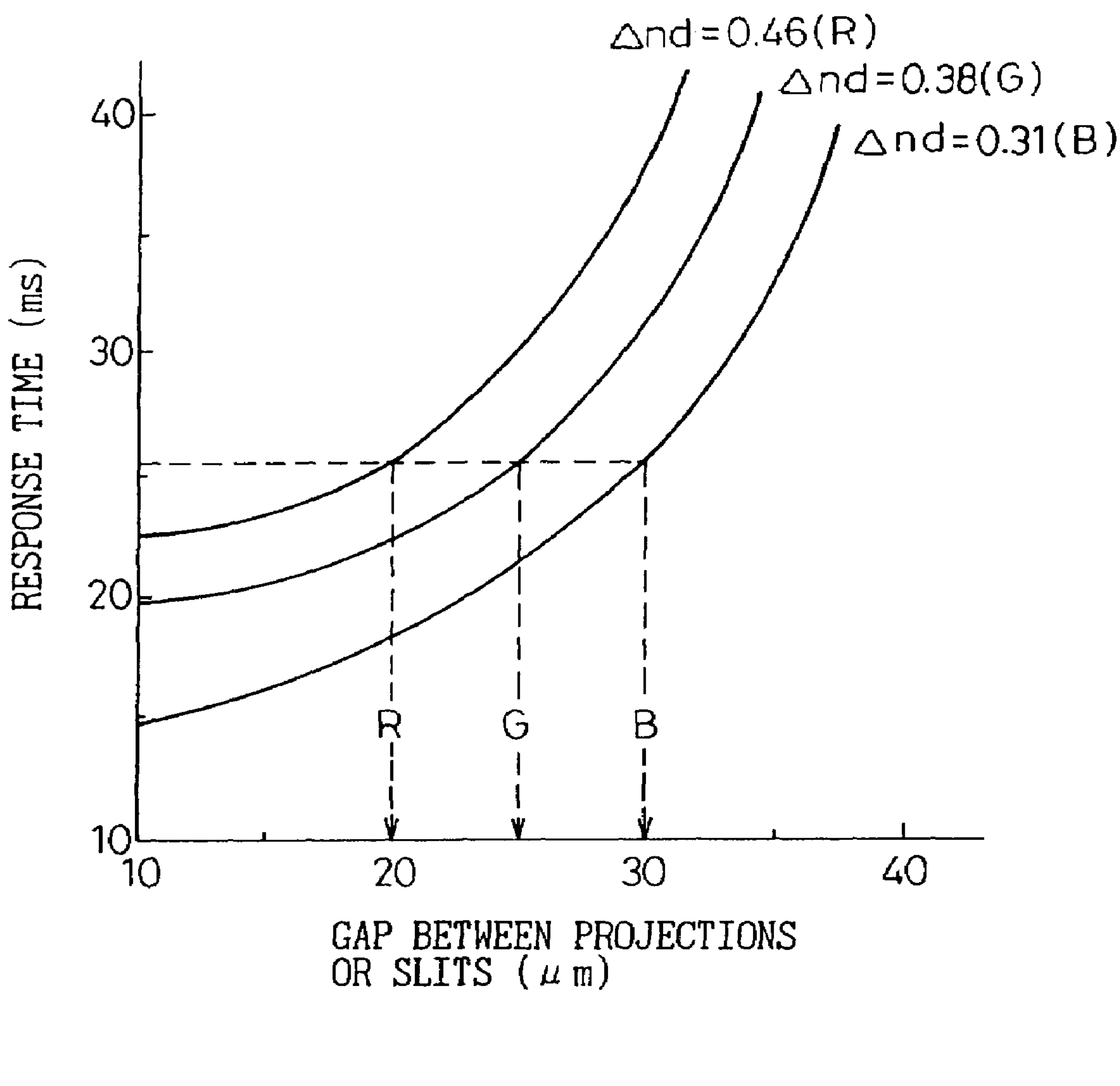

Δnd=0.46(R)
Δnd=0.38(G)
Δnd=0.31(B)
40
30
20
10
RESPONSE TIME (ms)
R
G
B
10
20
30
40
GAP BETWEEN PROJECTIONS OR SLITS (μm)

Fig.130

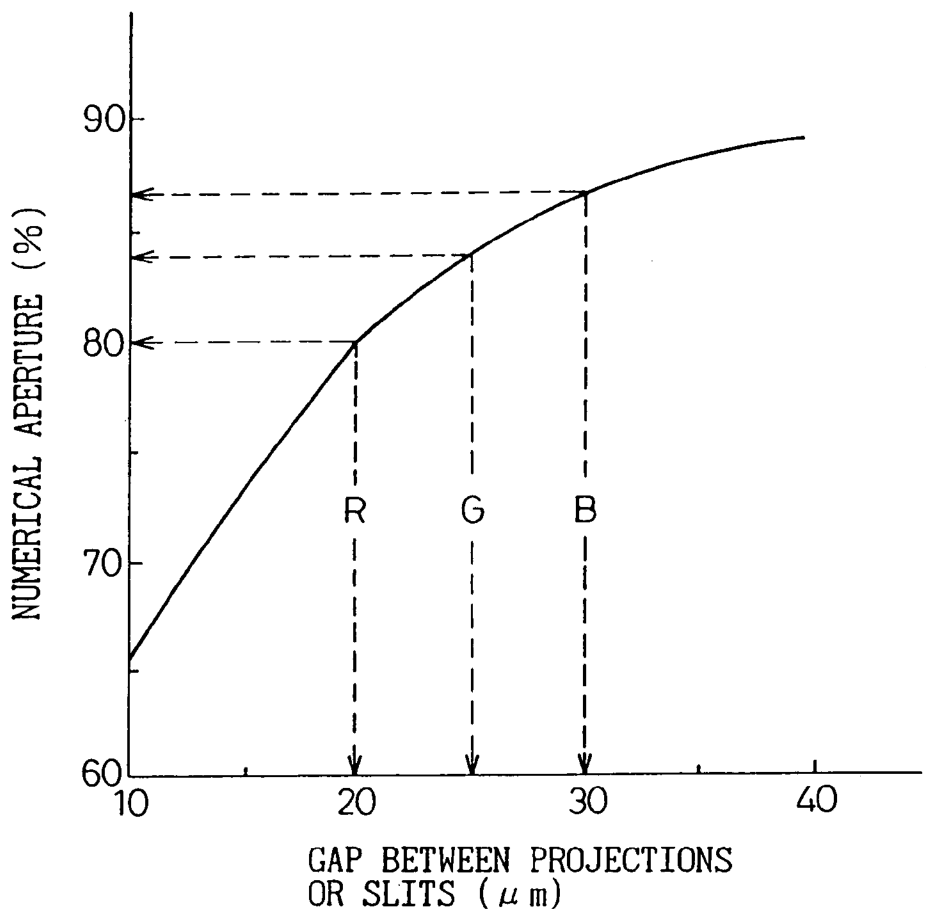

90
80
70
60
NUMERICAL APERTURE (%)
R
G
B
10
20
30
40
GAP BETWEEN PROJECTIONS
OR SLITS (μm)

Fig.131

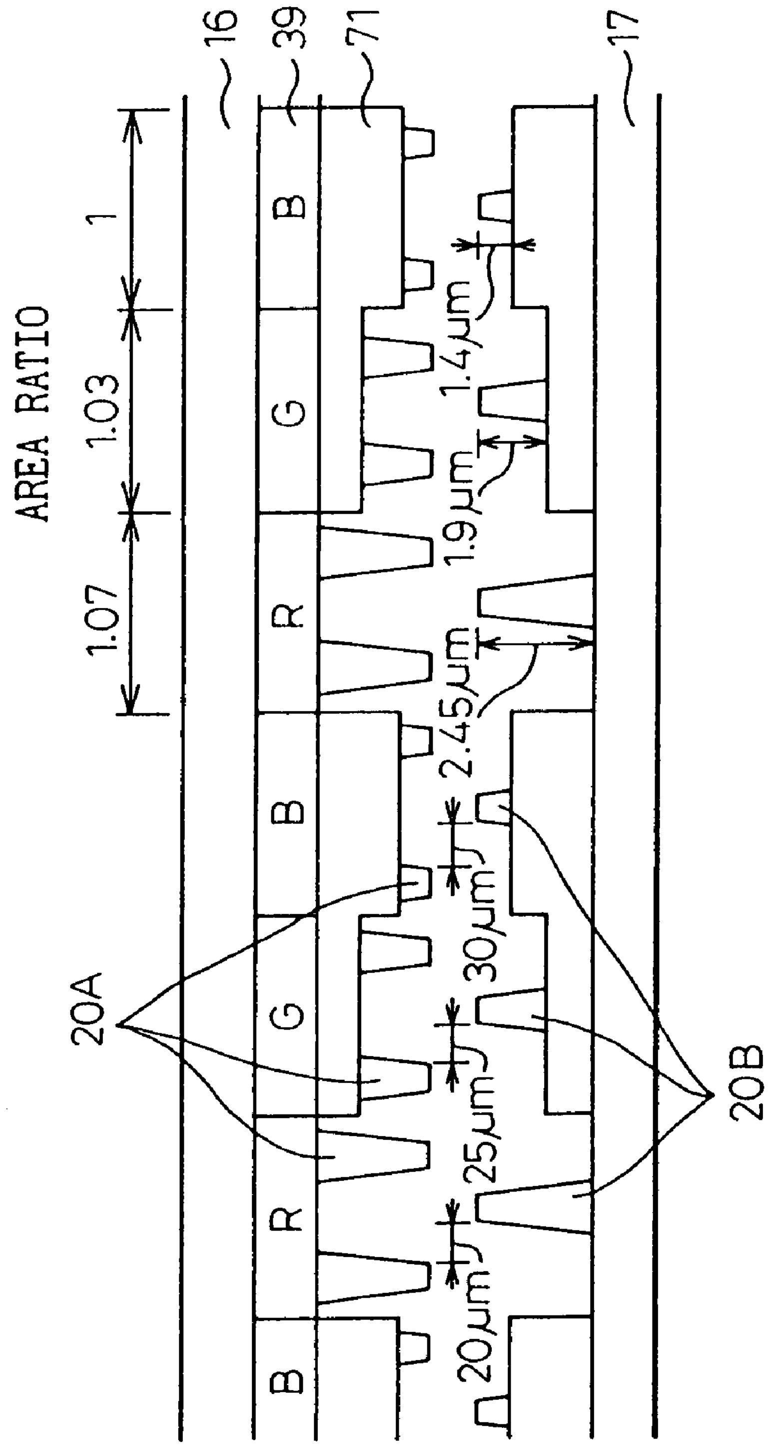

AREA RATIO
1
1.03
1.07
16
39
71
17
B
G
R
B
G
R
B
1.4μm
1.9μm
2.45μm
20μm
25μm
30μm
20A
20B

Fig.132

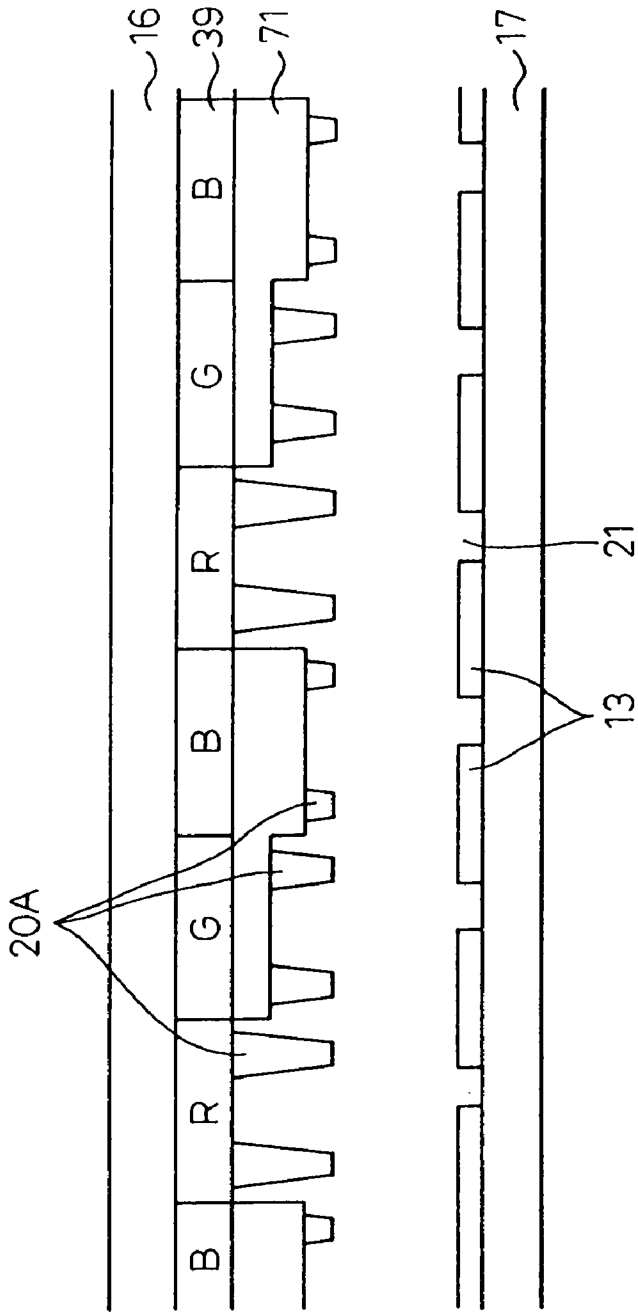


Fig.133

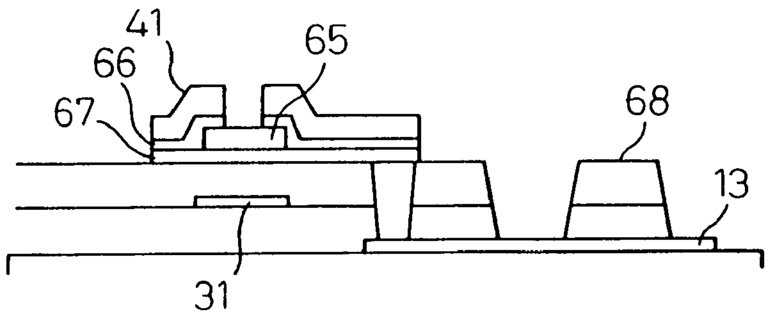


Fig.134A

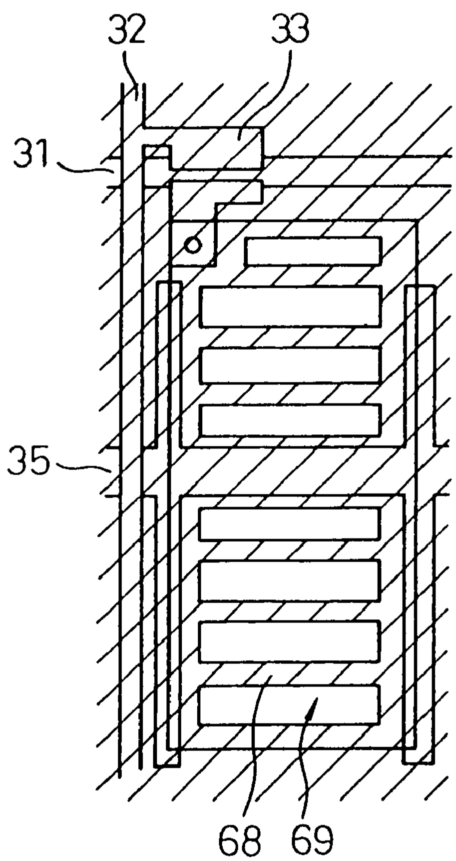


Fig.134B

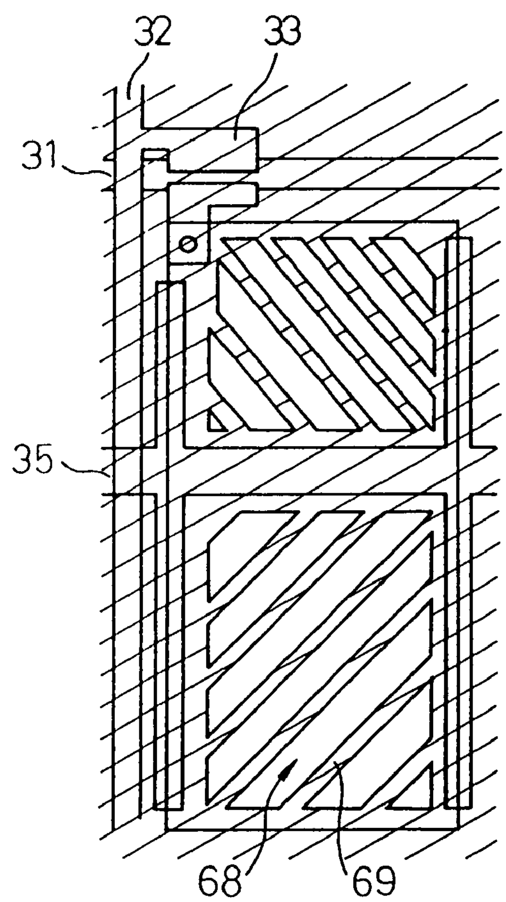


Fig.135

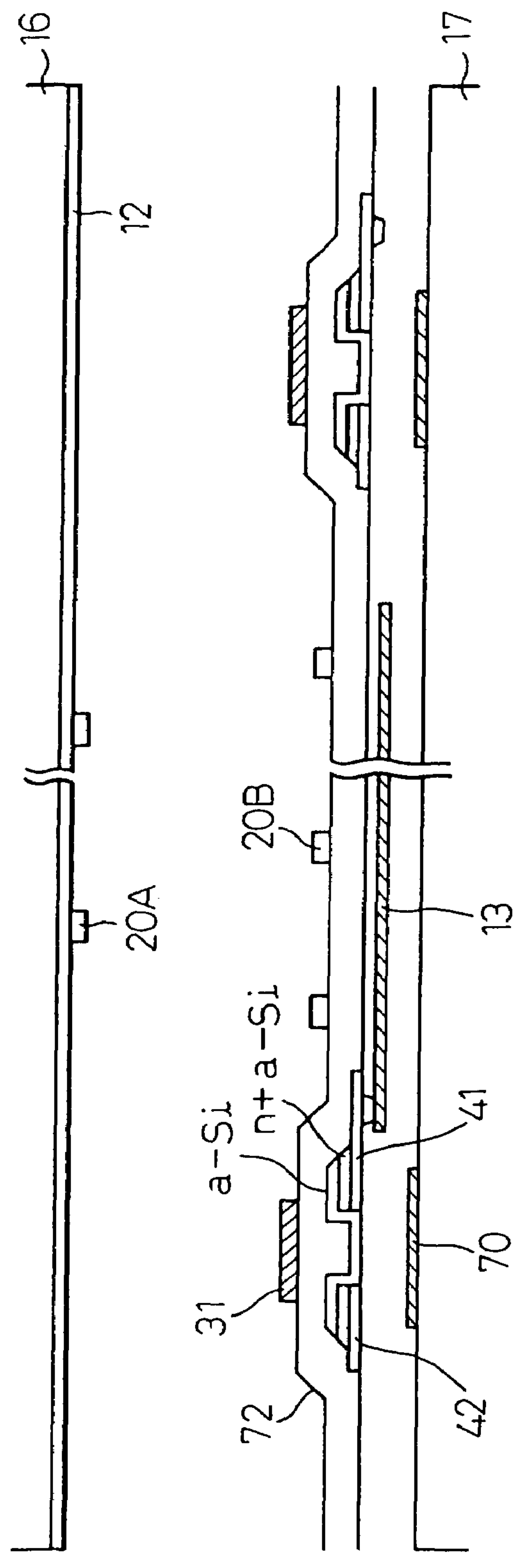


Fig.136A

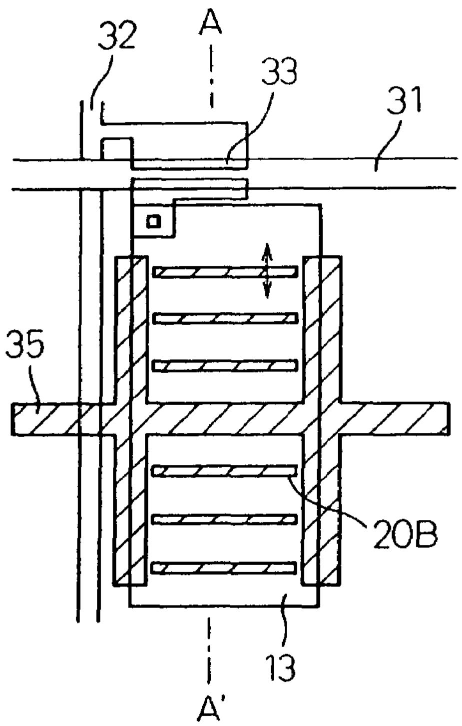
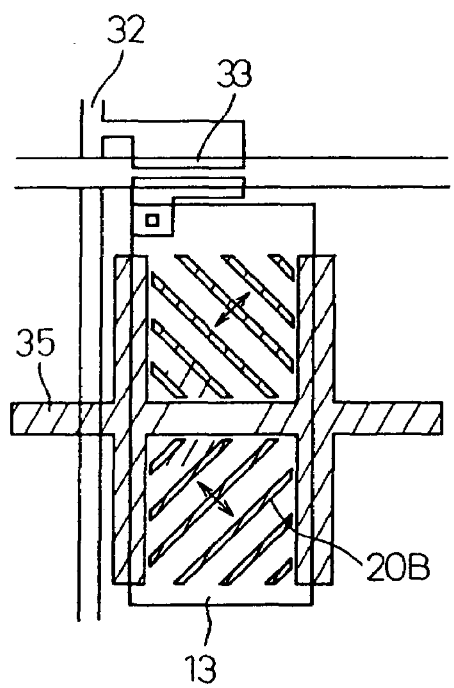


Fig.136B



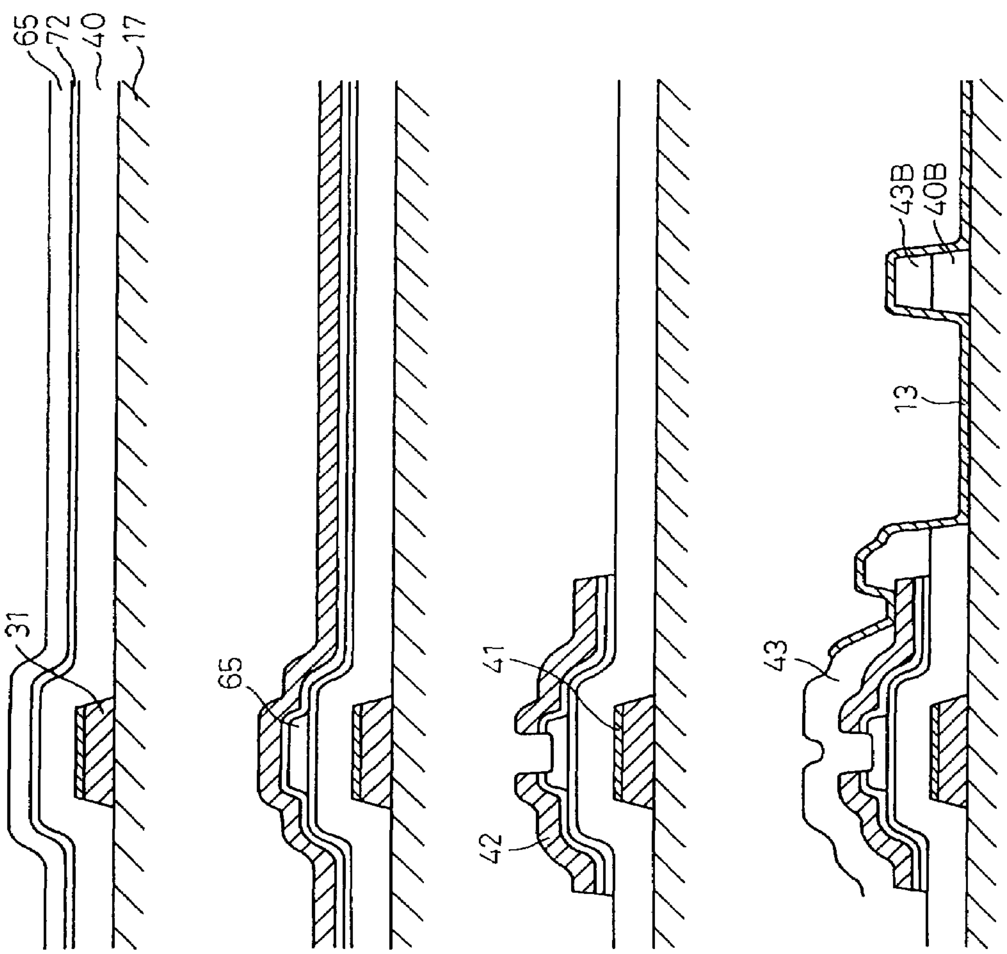


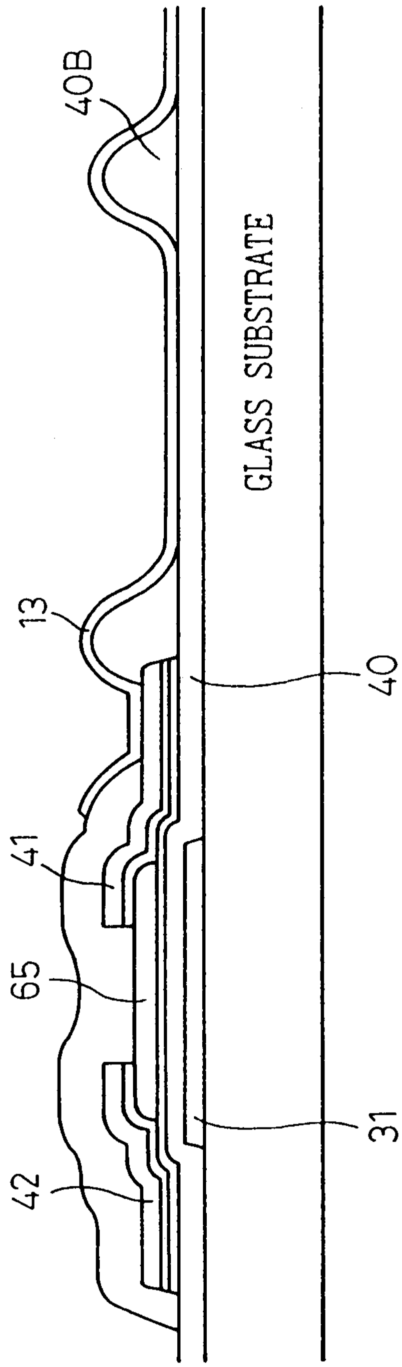
Fig.137A

Fig.137B

Fig.137C

Fig.137D

Fig.138



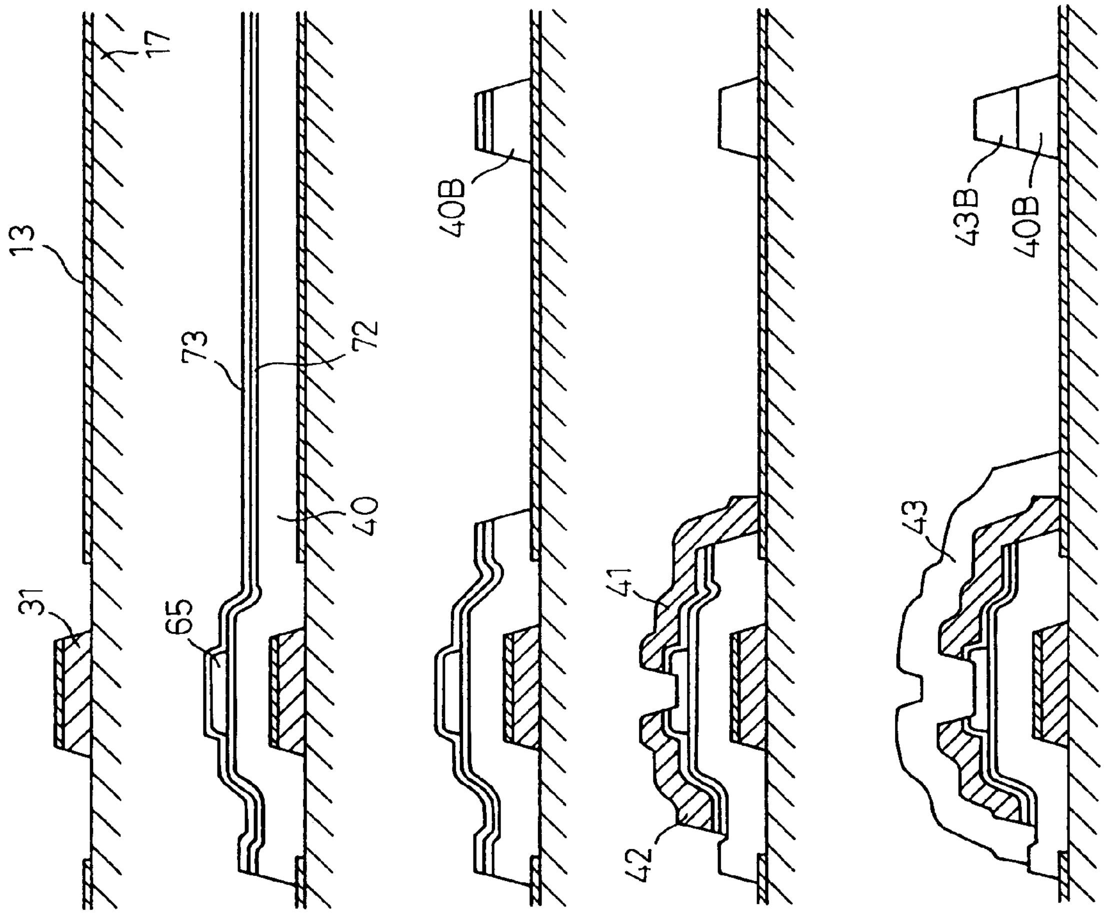


Fig.139A

Fig.139B

Fig.139C

Fig.139D

Fig.139E

Fig.140A

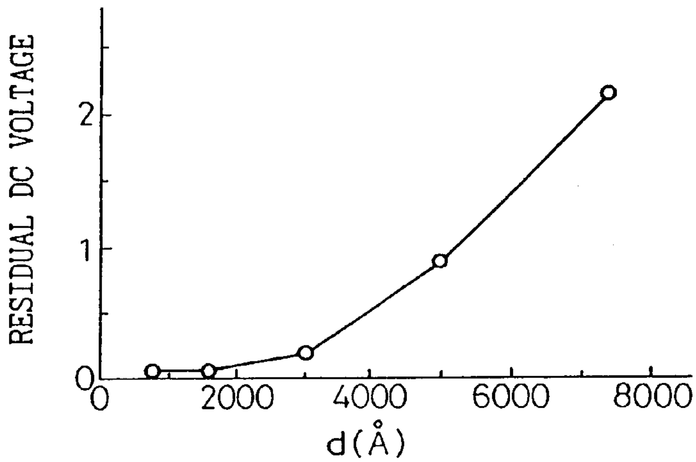


Fig.140B

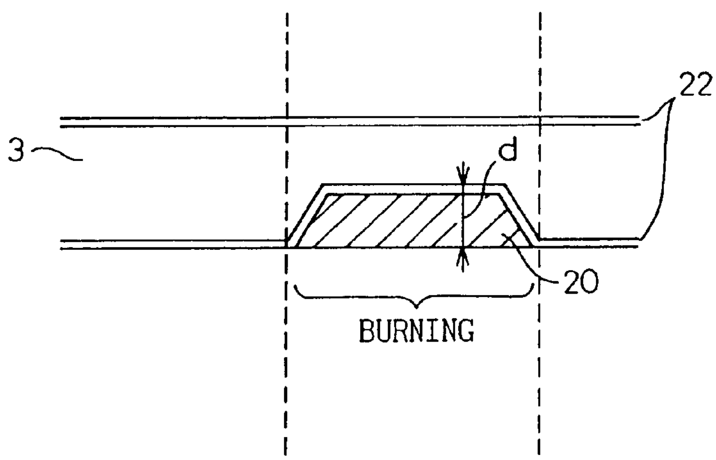


Fig.141A

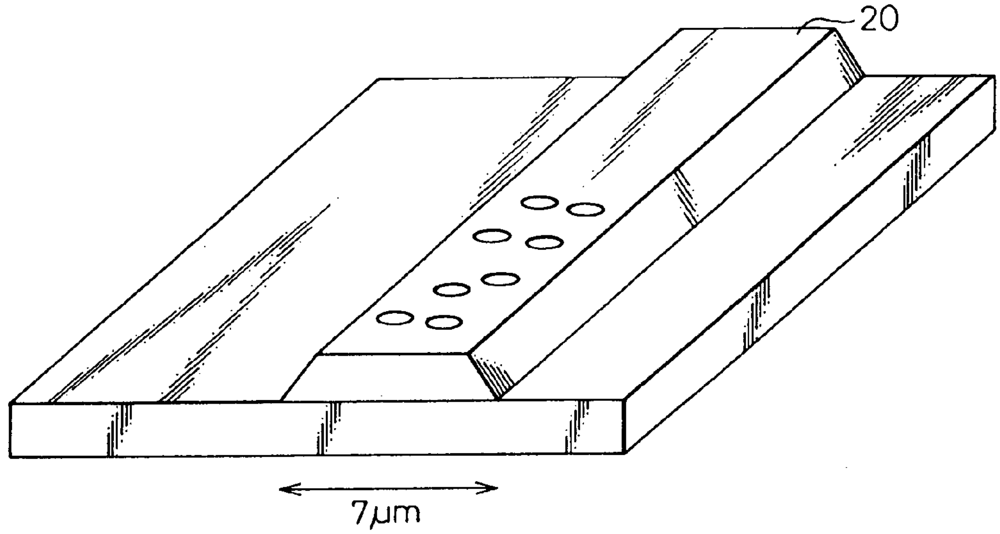


Fig.141B

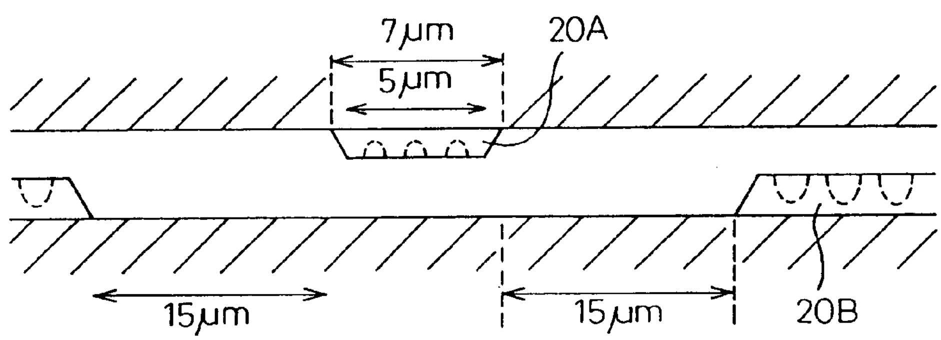


Fig.142A

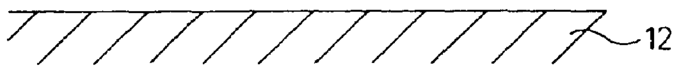


Fig.142B

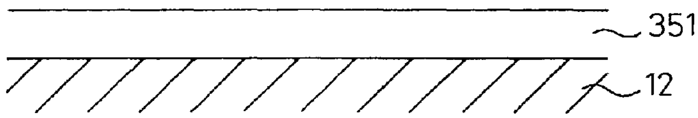


Fig.142C

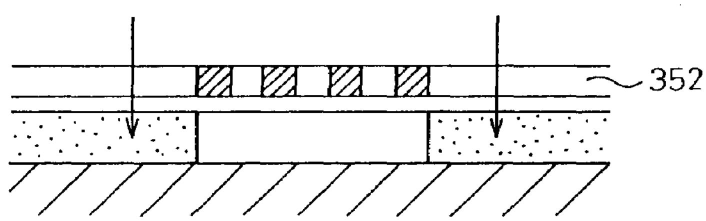


Fig.142D

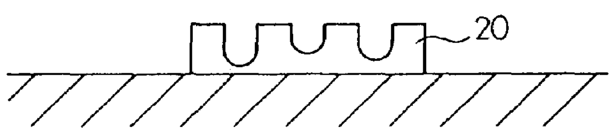


Fig.142E

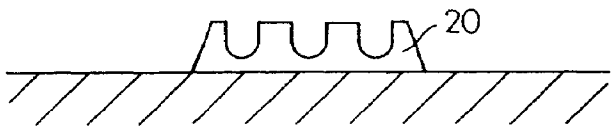


Fig.143

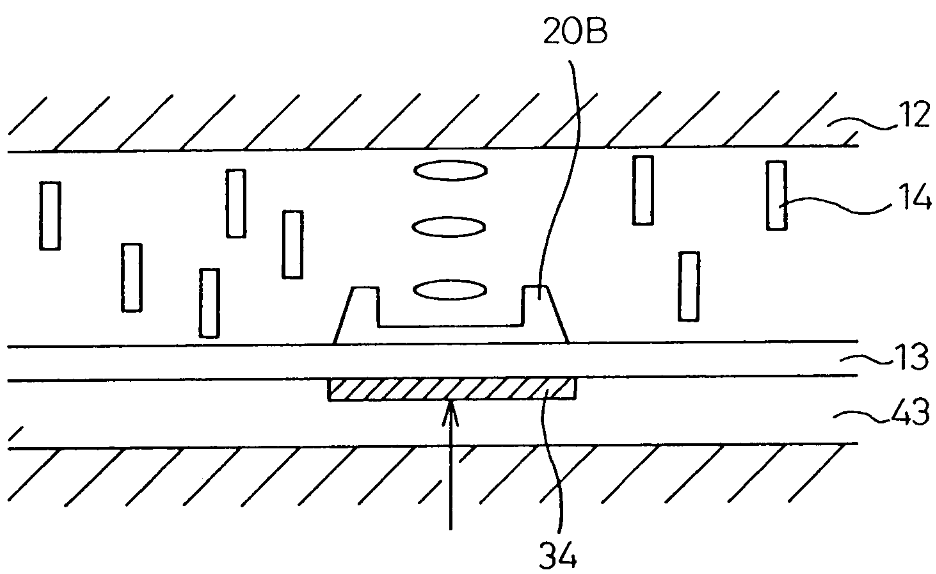


Fig.144A

BEFORE BAKING

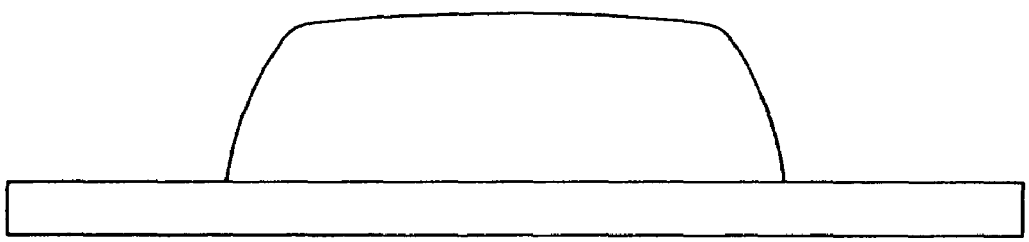


Fig.144B

AFTER BAKING

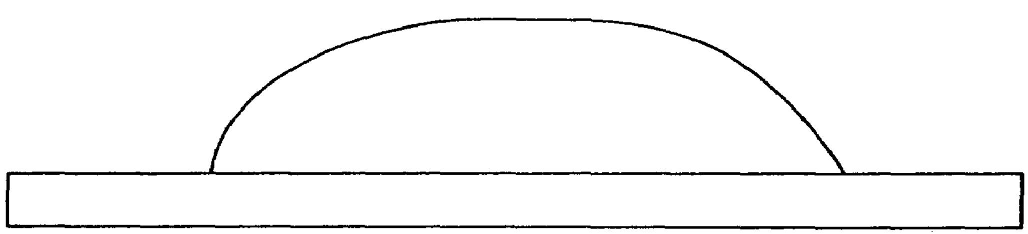


Fig.145A NO BAKING

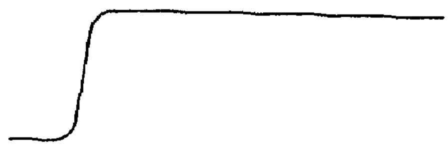


Fig.145B 120℃

Fig.145C 130℃

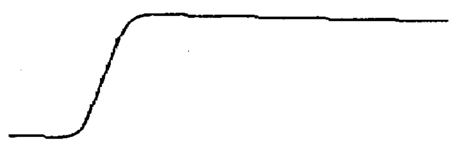


Fig.145D 140℃

Fig.145E 150℃

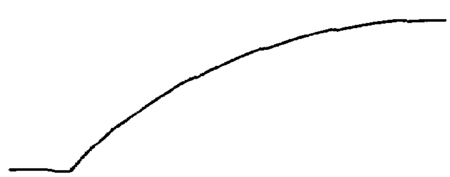


Fig.146A

2μm WIDTH

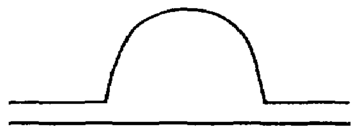


Fig.146B

5μm WIDTH

Fig.146C

10μm WIDTH

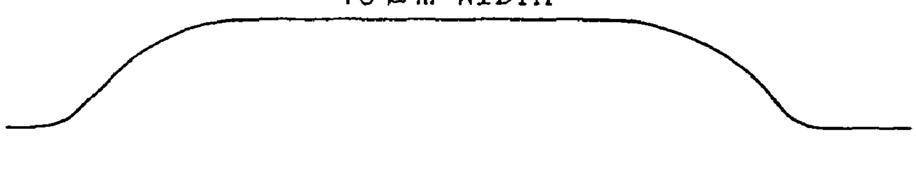


Fig.147A

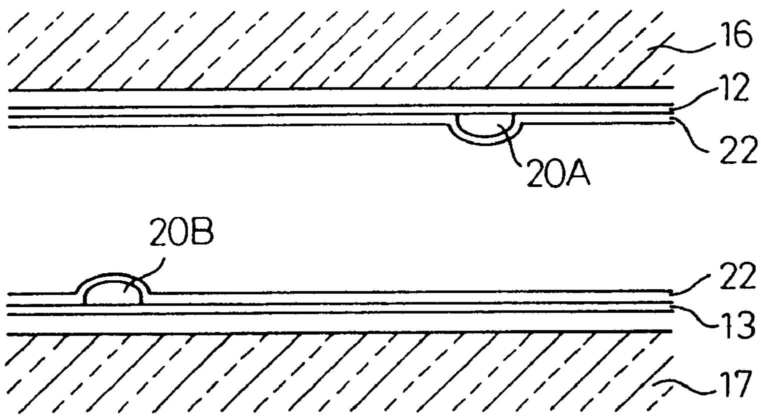


Fig.147B

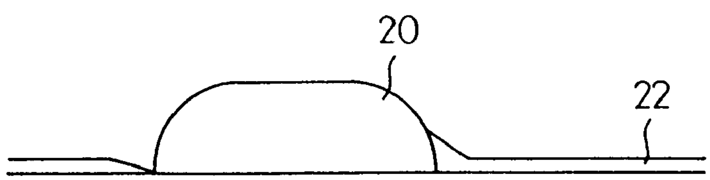


Fig.148A

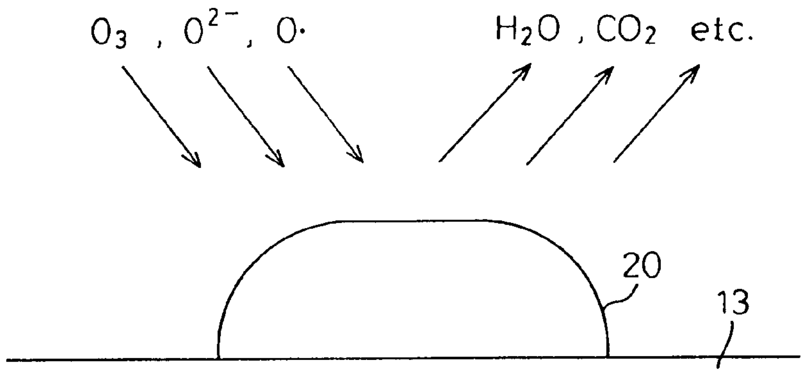


Fig.148B

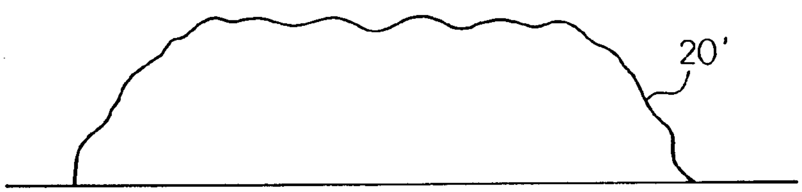


Fig.148C

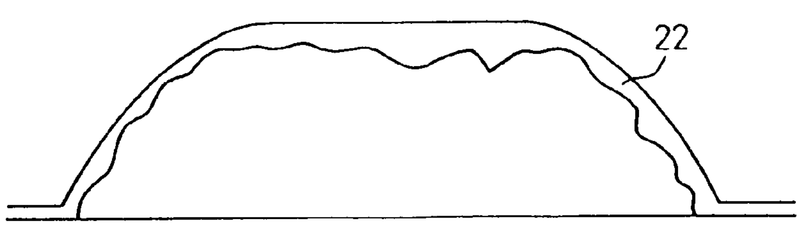


Fig.149A

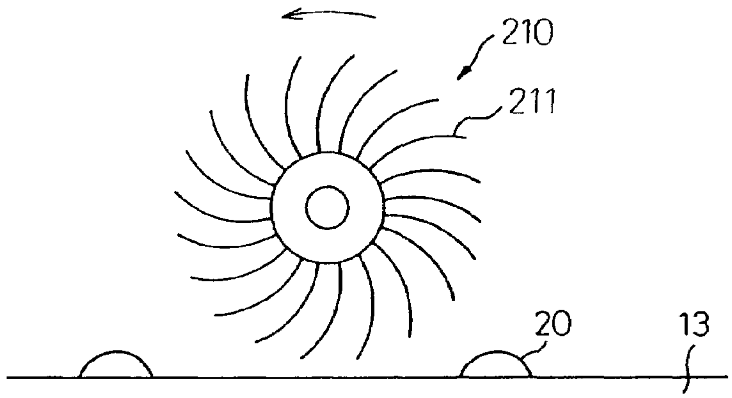


Fig.149B

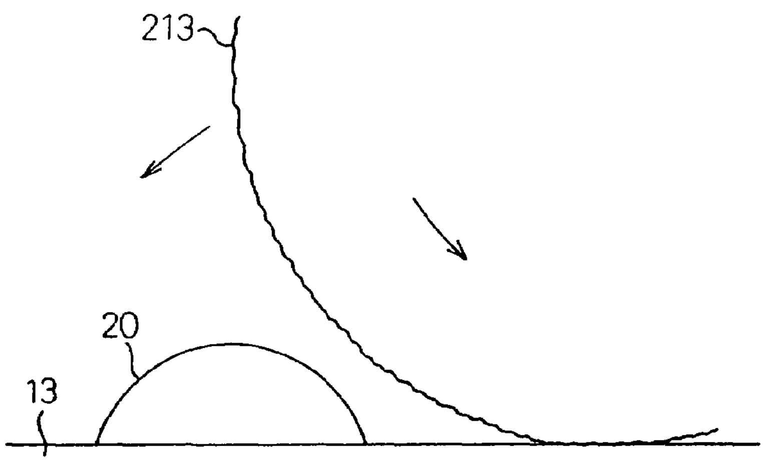


Fig.150

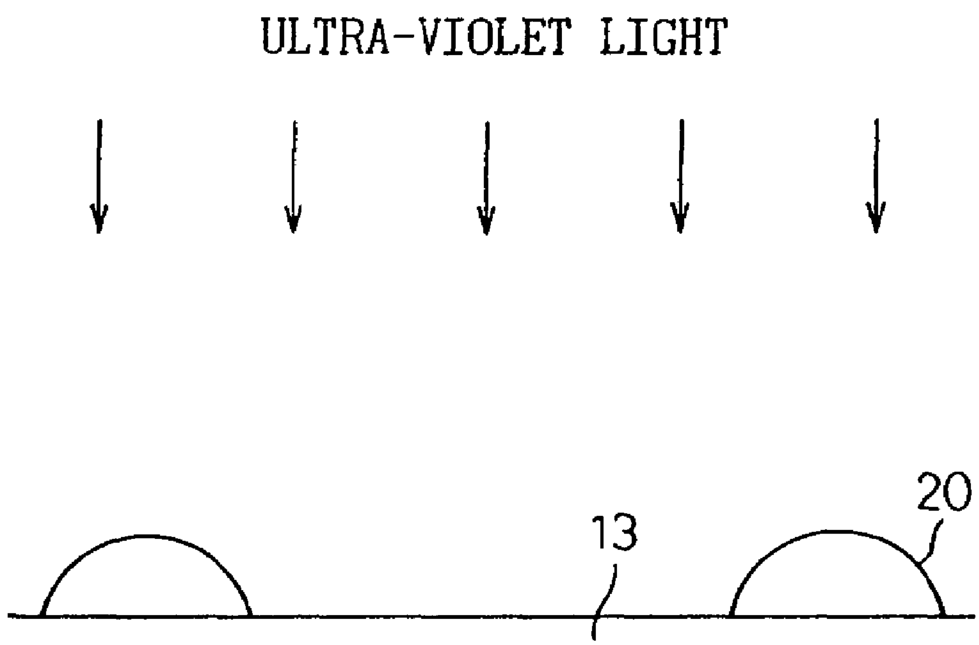


Fig.151A

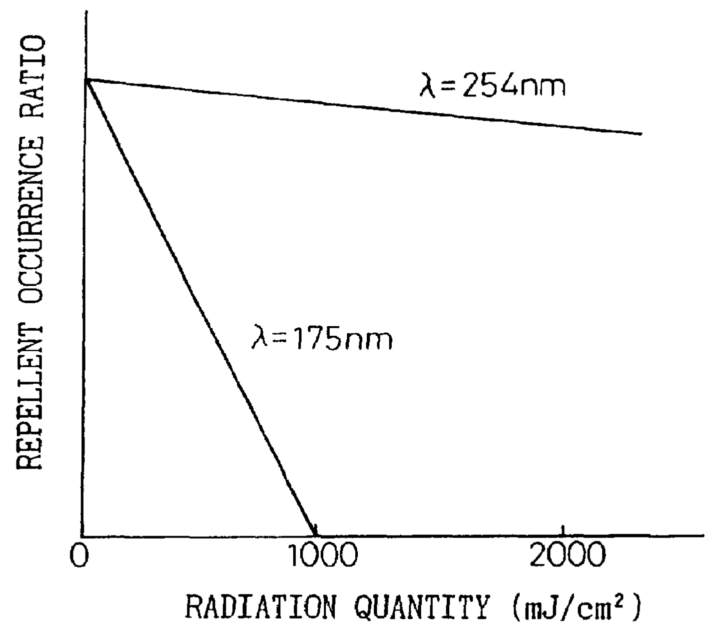


Fig.151B

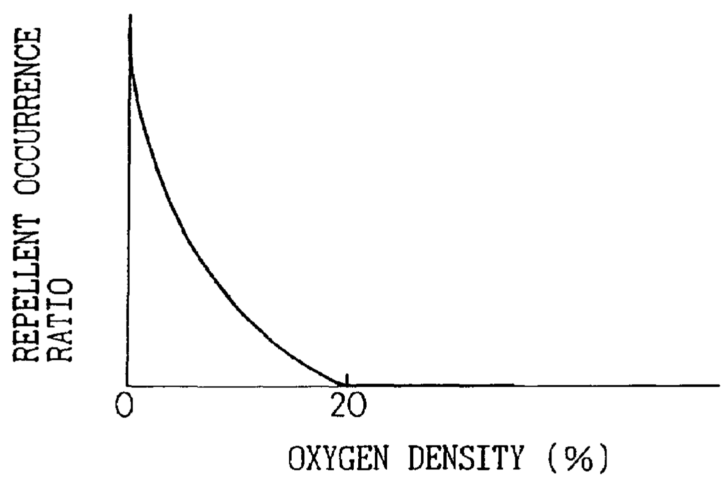


Fig.152A

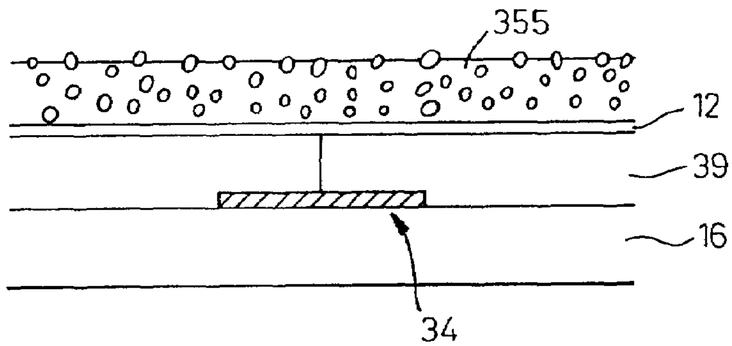


Fig.152B

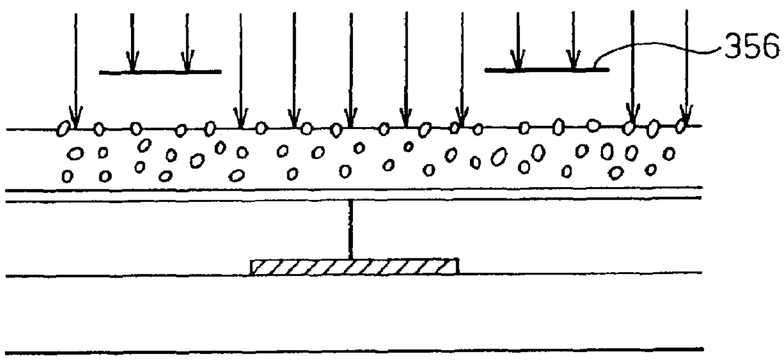


Fig.152C

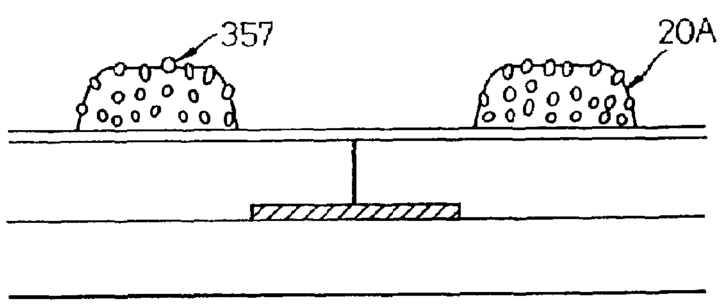


Fig.153A

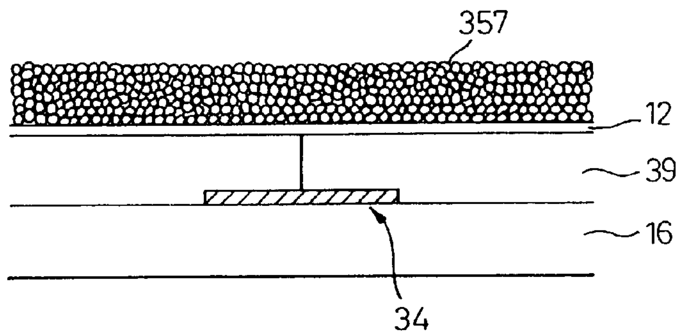


Fig.153B

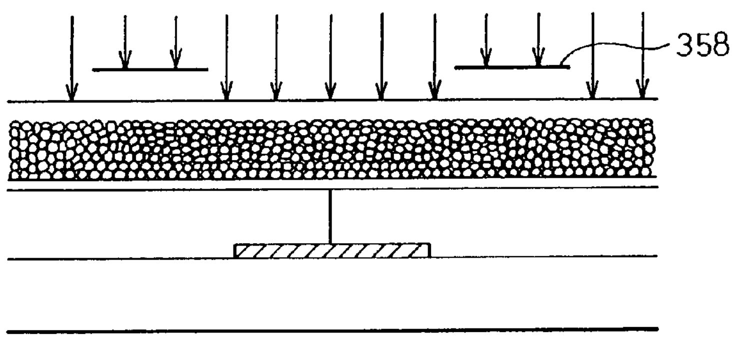


Fig.153C

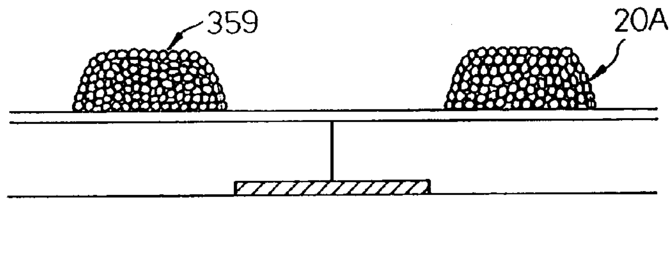


Fig.154A

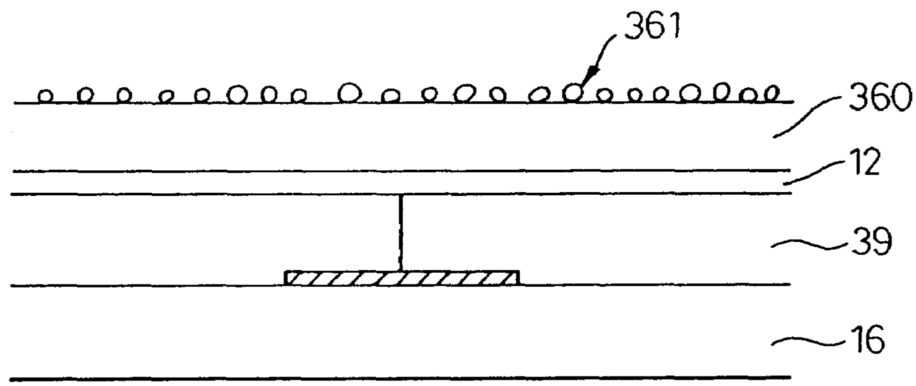


Fig.154B

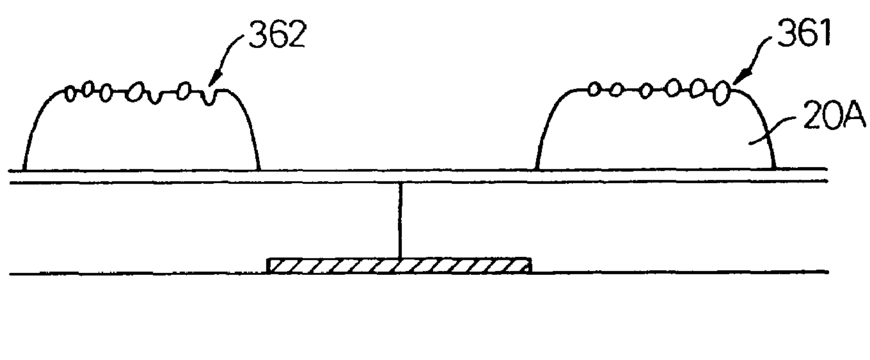


Fig.155A

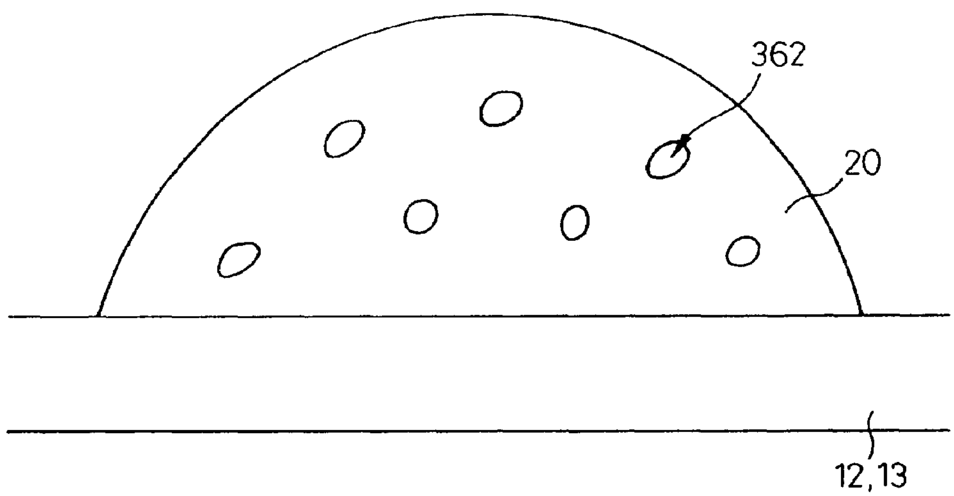


Fig.155B

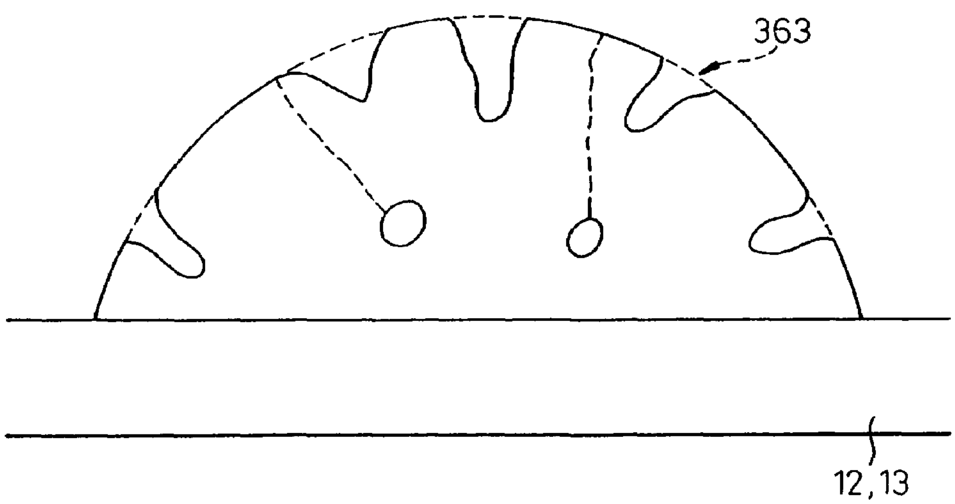


Fig.156

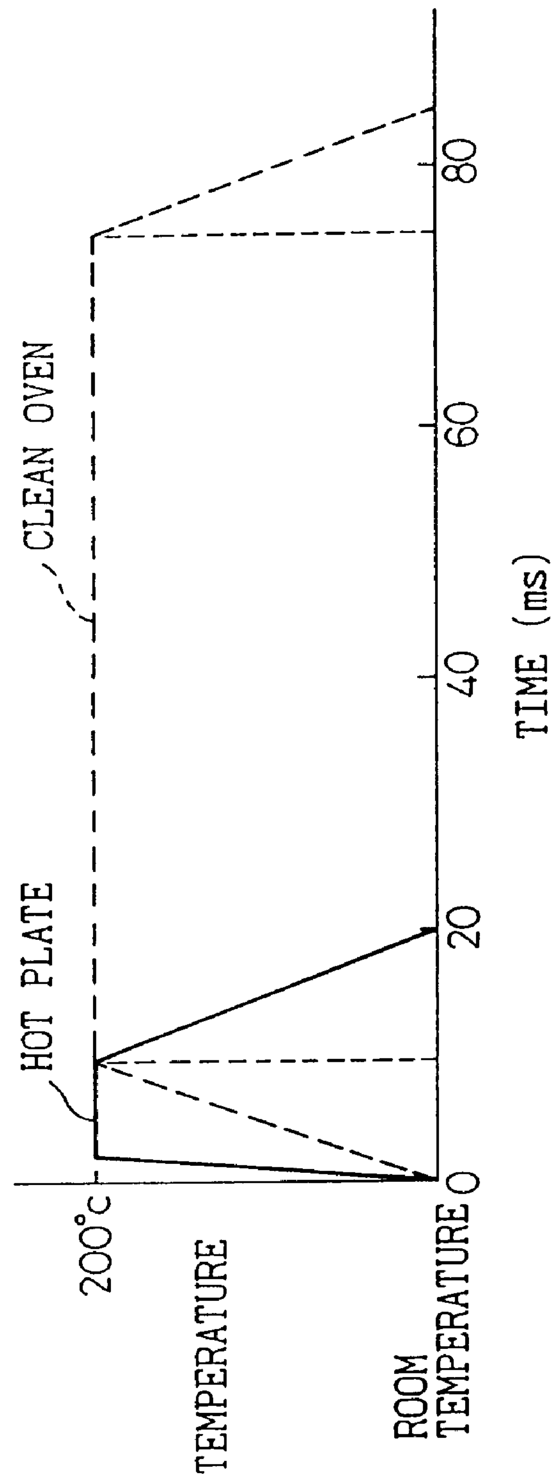

HOT PLATE
CLEAN OVEN
200°C
TEMPERATURE
ROOM TEMPERATURE
0
20
40
60
80
TIME (ms)

Fig.157A

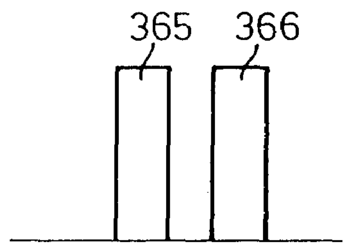


Fig.157B

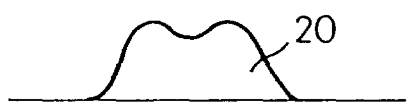


Fig.157C

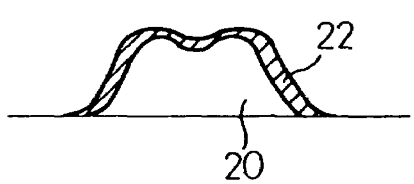


Fig.158

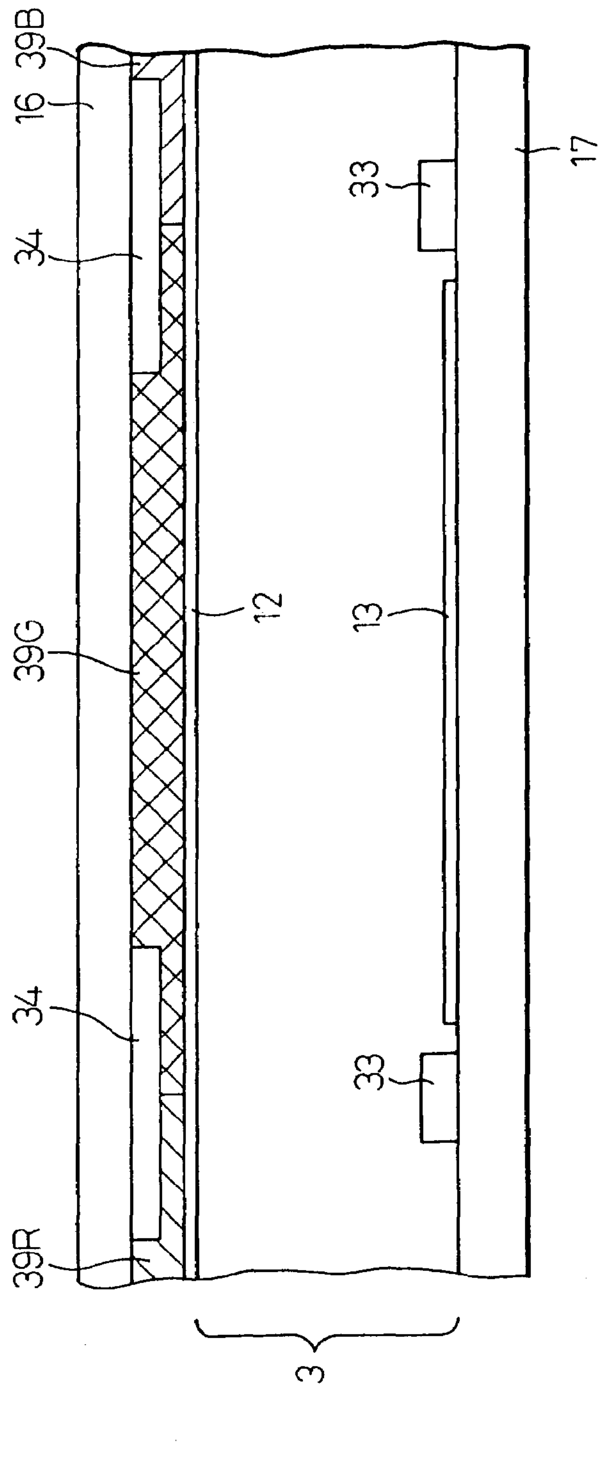


Fig.159

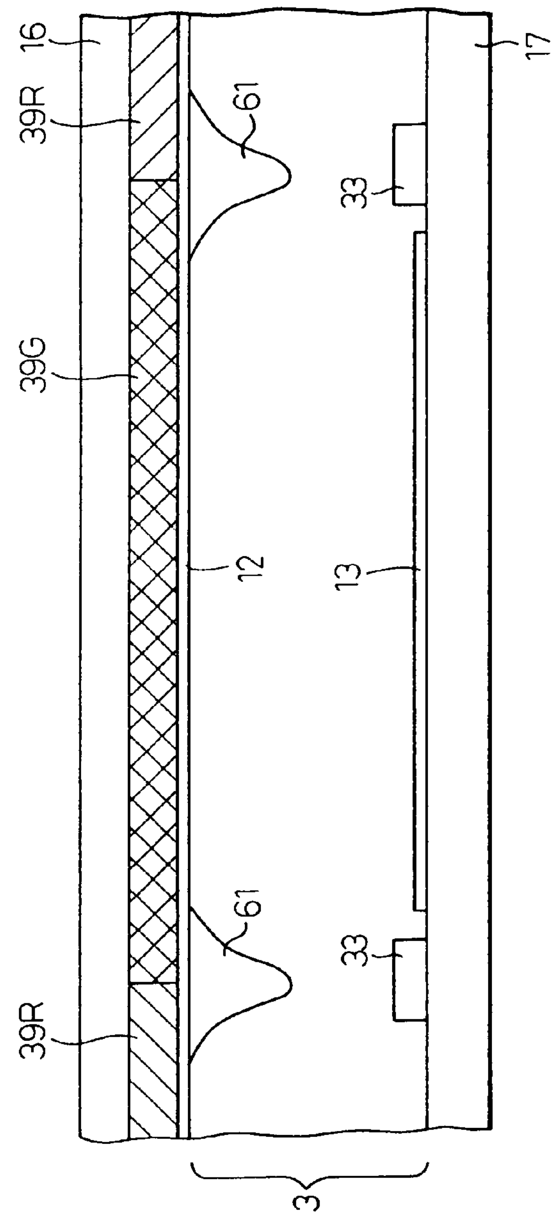


Fig.160

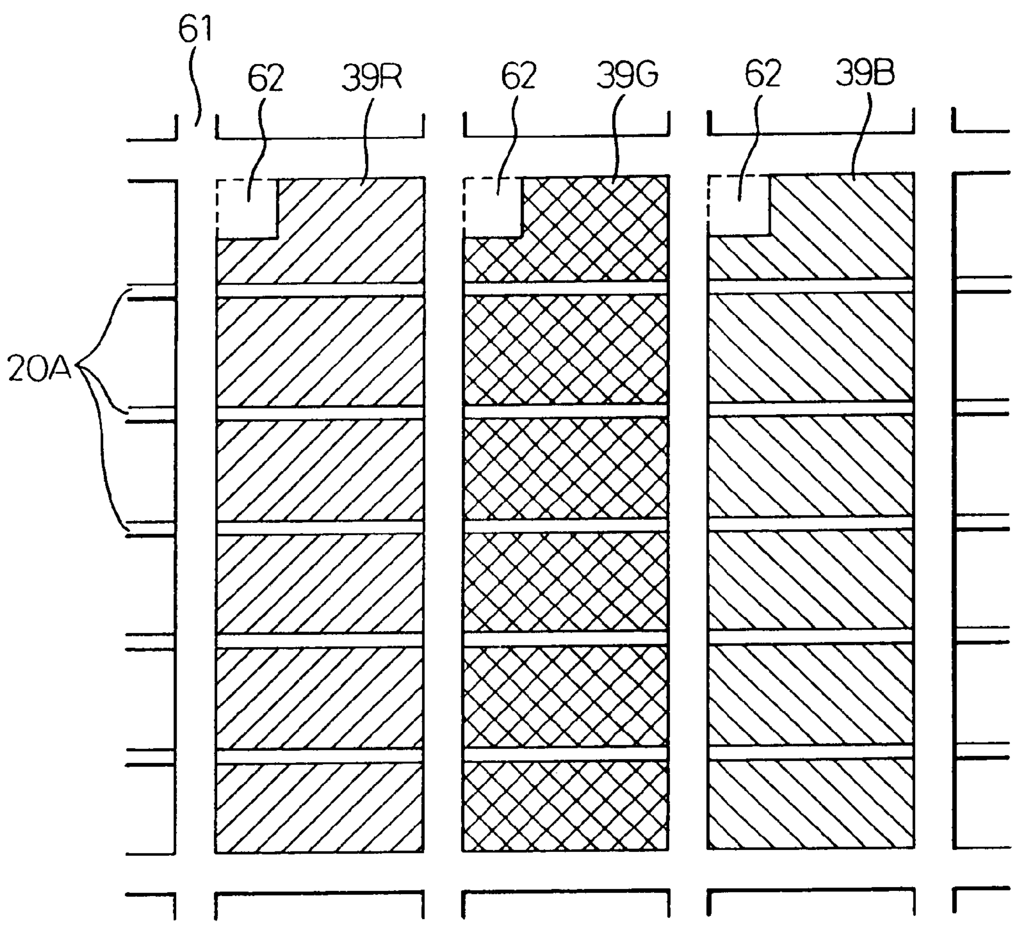
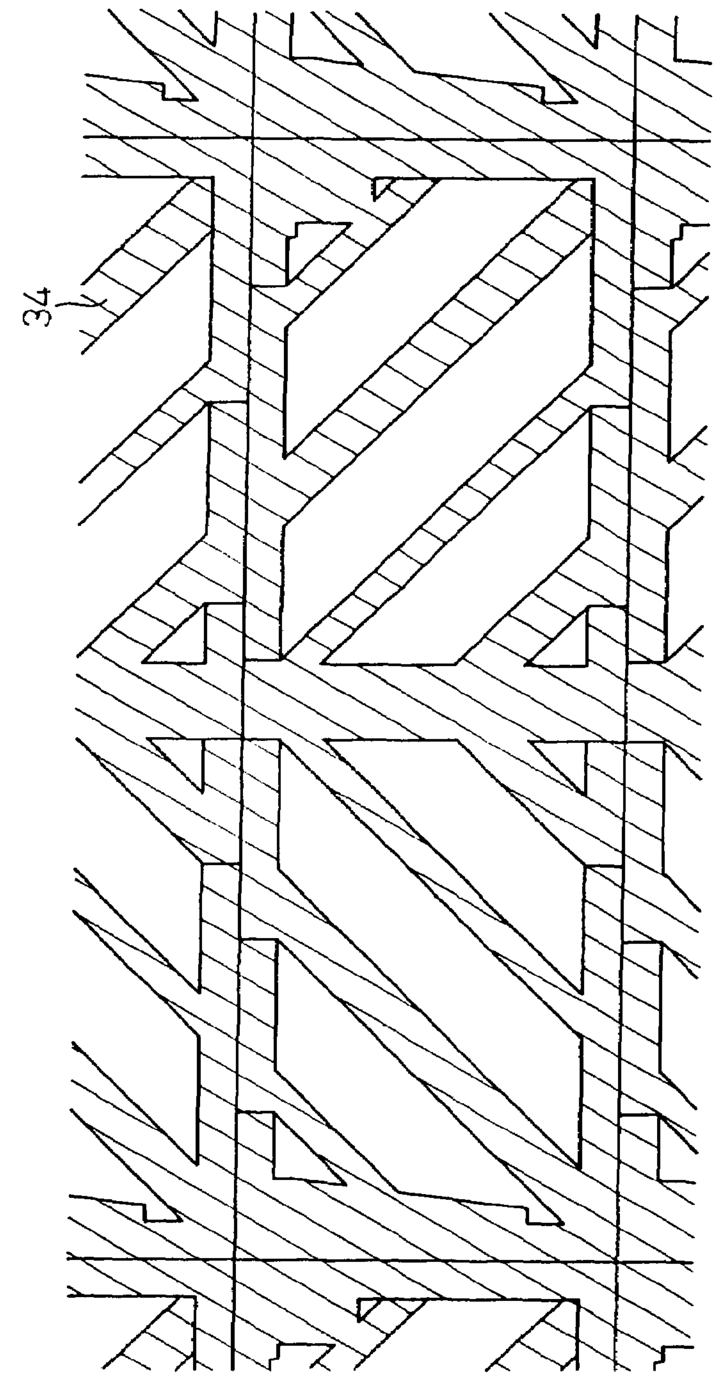


Fig.161



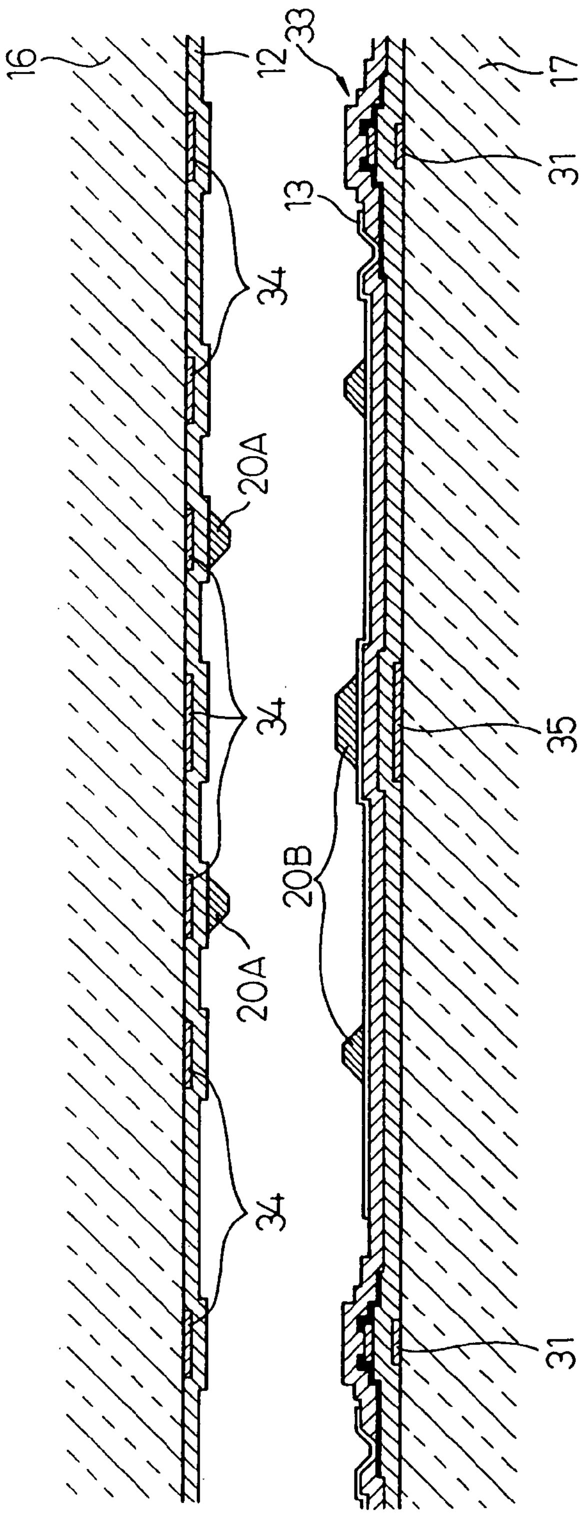


Fig.162

Fig.163

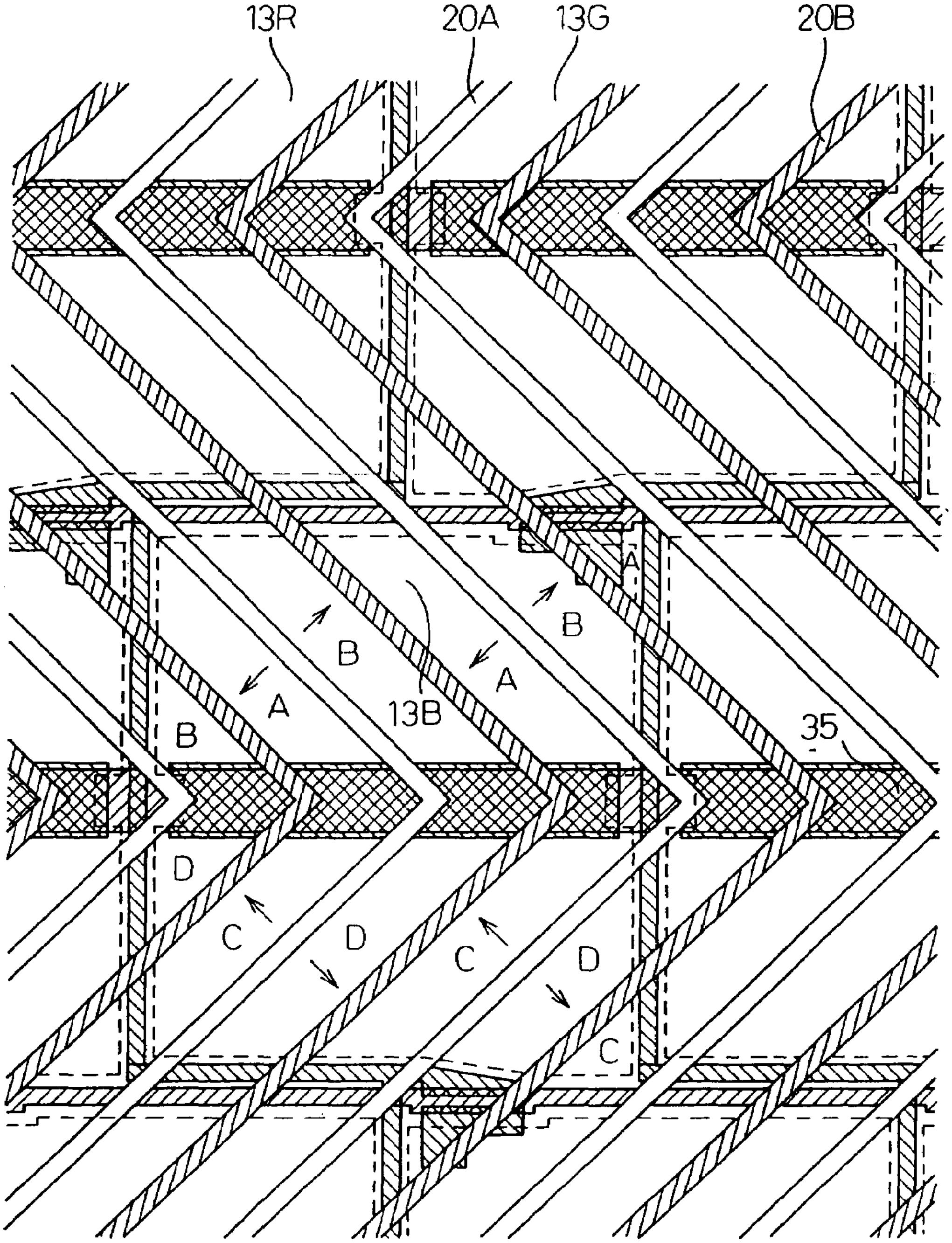


Fig.164

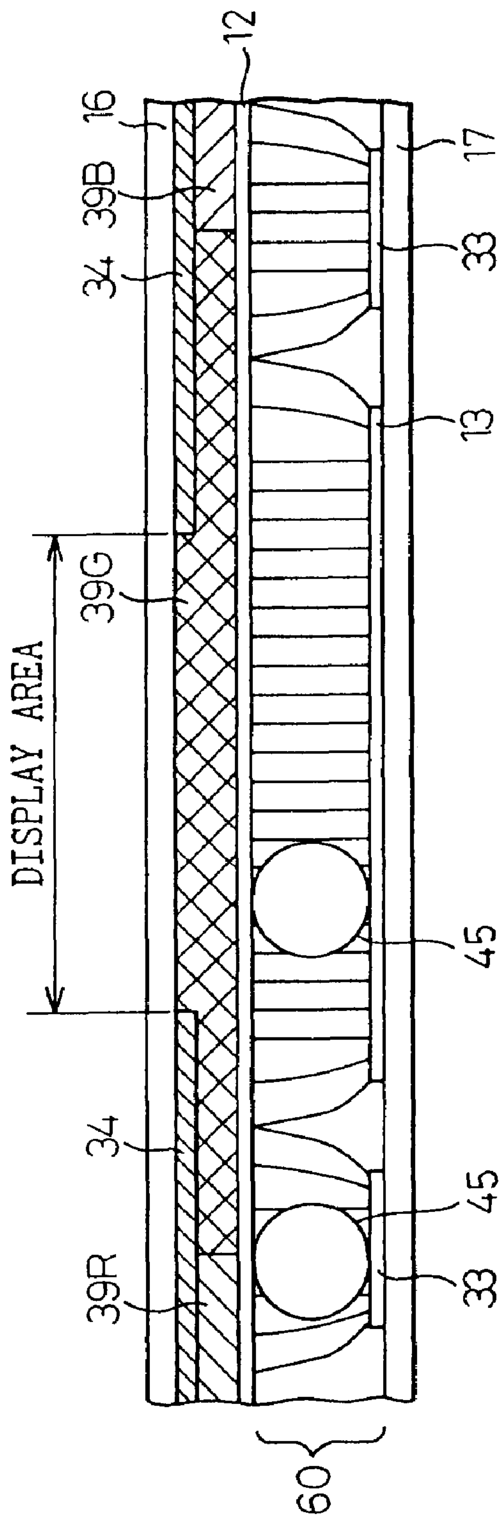


Fig.165A

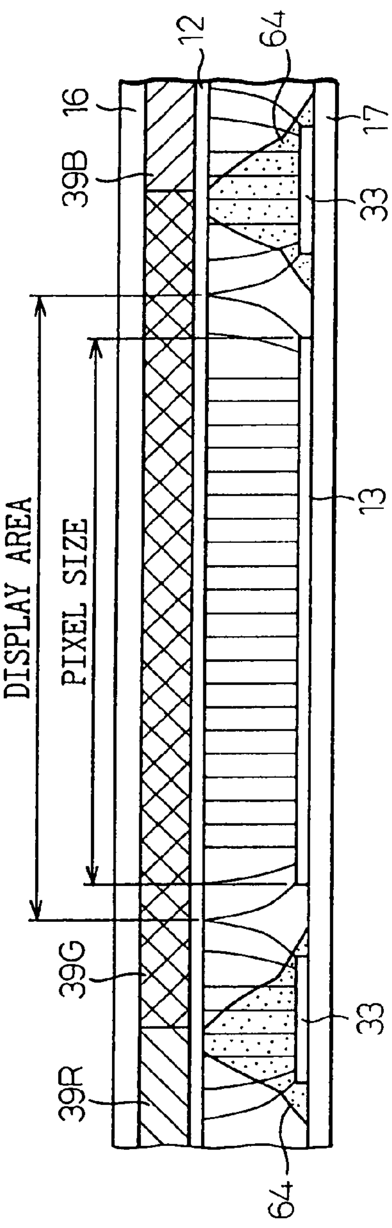
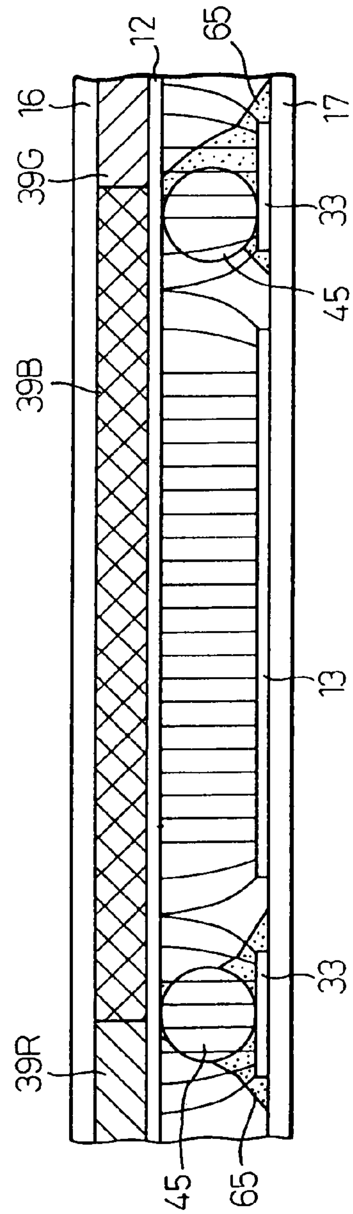


Fig.165B



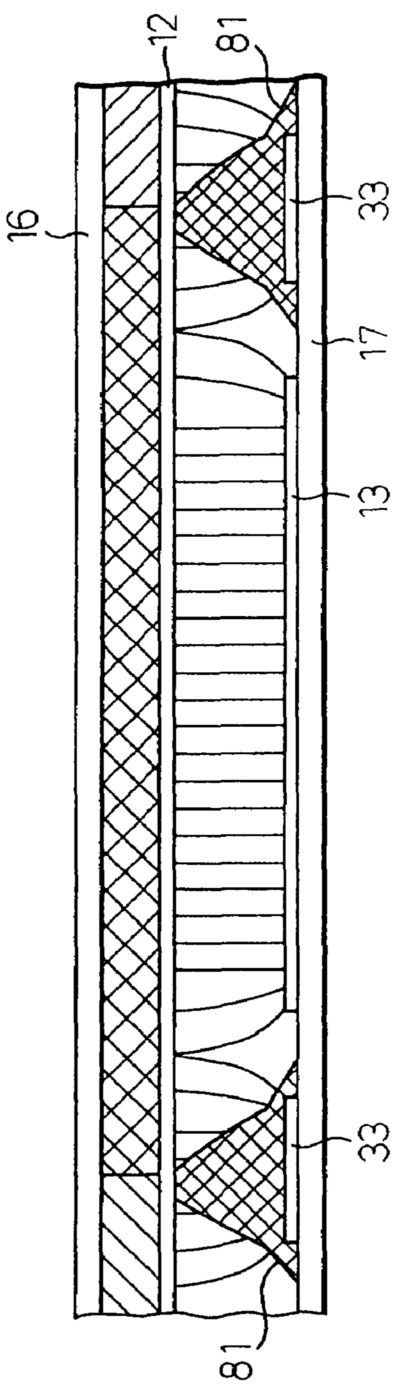


Fig.166A

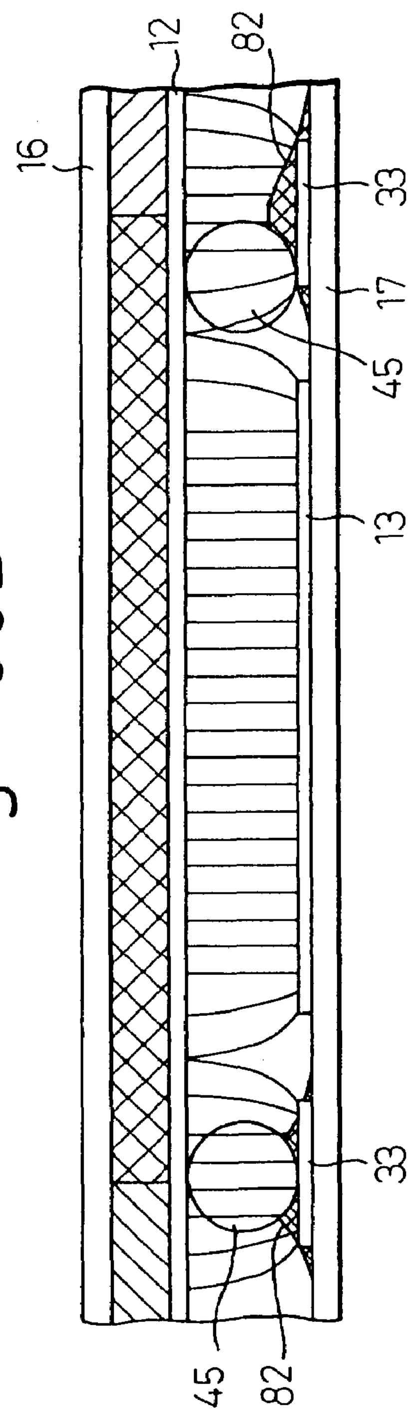


Fig.166B

Fig.167

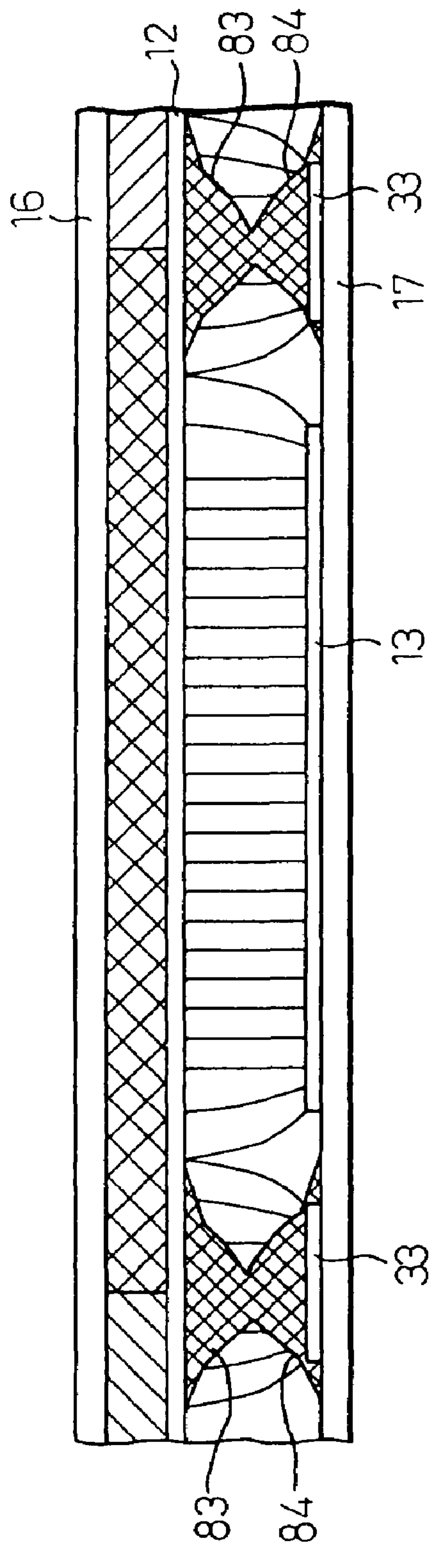


Fig.168A

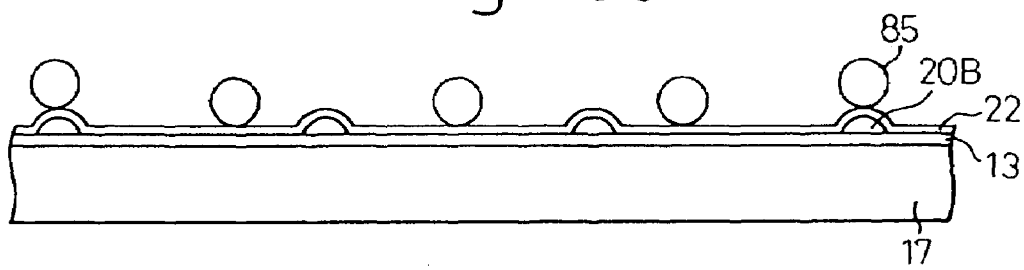


Fig.168B

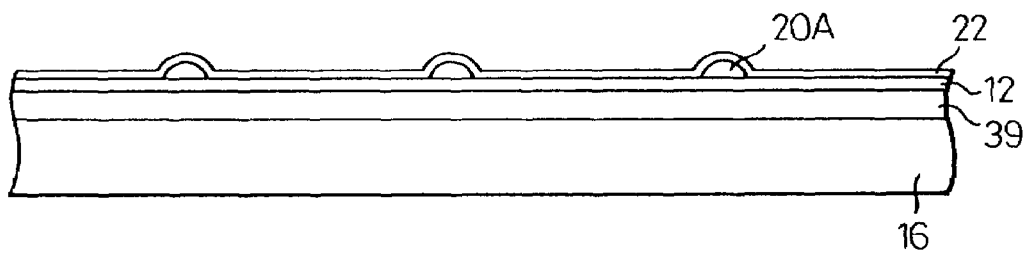


Fig.168C

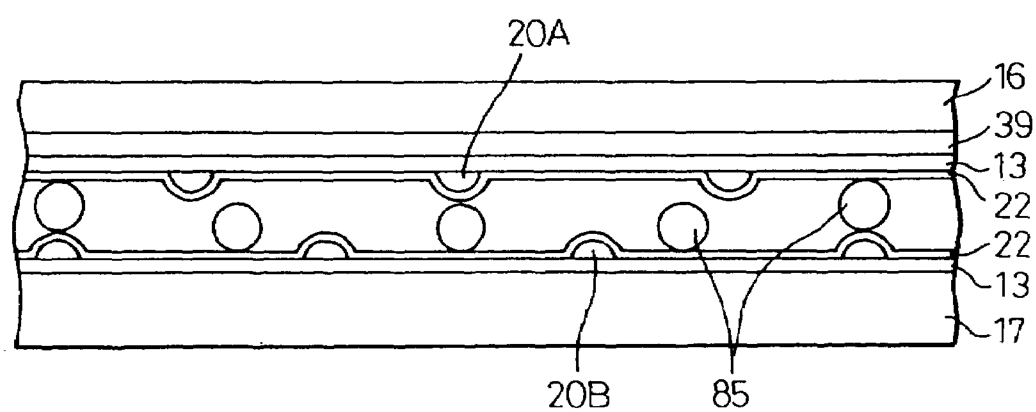


Fig.169

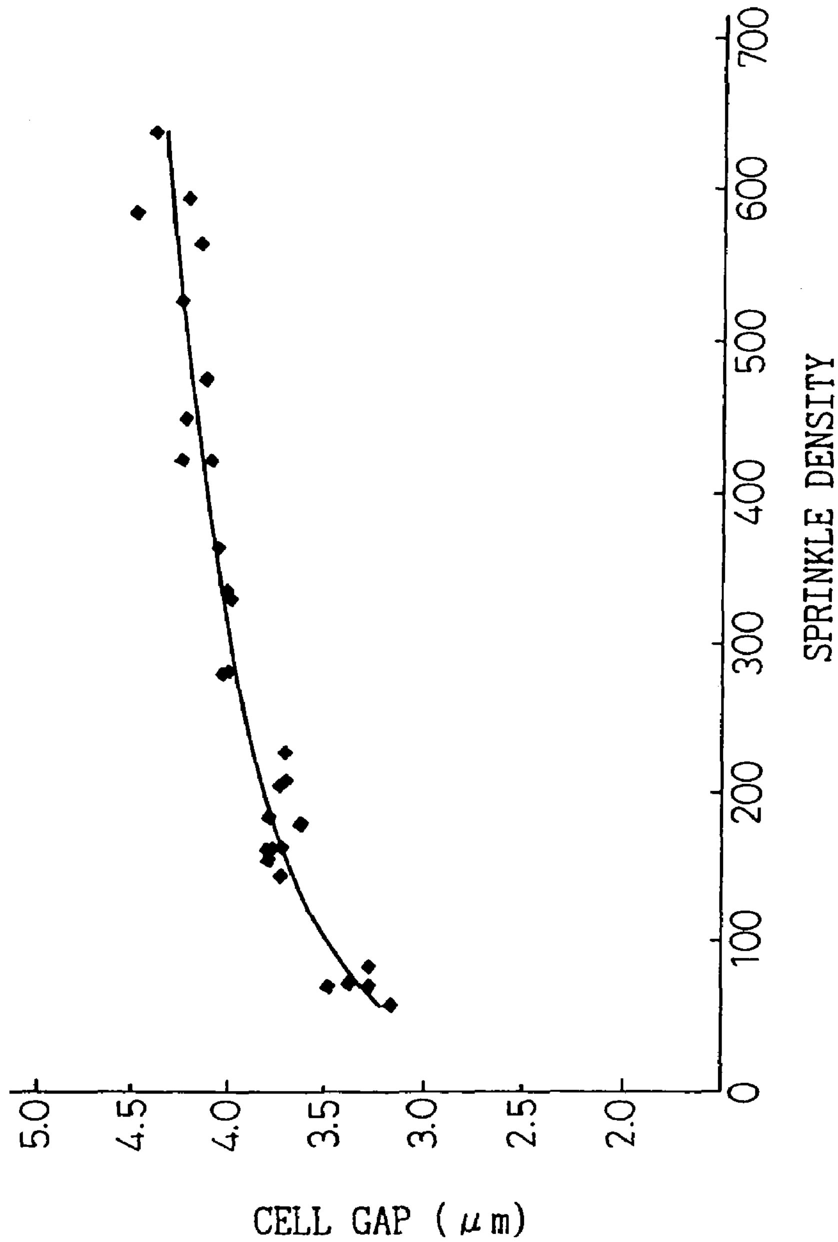
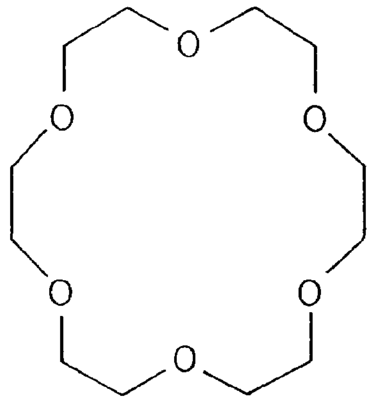

CELL GAP (μm)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
SPRINKLE DENSITY
0
100
200
300
400
500
600
700

Fig.170

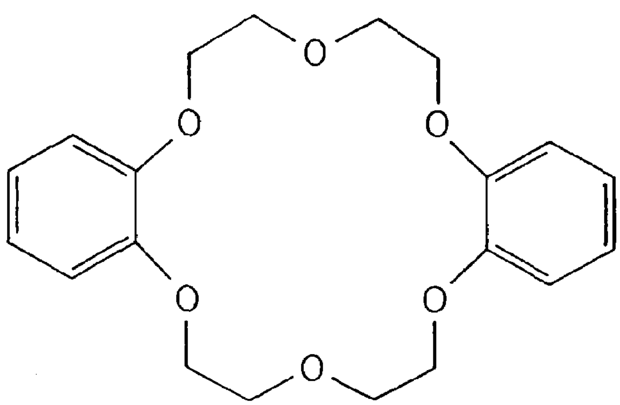
SPRINKLE DENSITY OF SPACERS (NUMBERS/mm^2)	50	100	150	200	250	300	350	400	450	500	550
BLEMISH OCCURRENCE DUE TO PUSHING	YES	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO
BLEMISH OCCURRENCE DUE TO PULLING	NO	NO	NO	NO	NO	NO	YES	YES	YES	YES	YES

Fig.171A



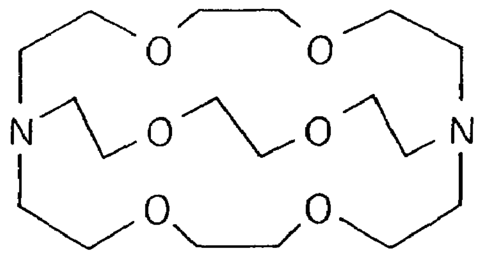
18-CROWN-6

Fig.171B



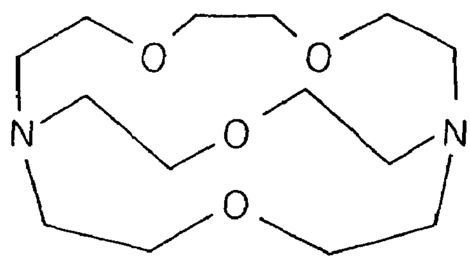
DIBENZOYL-18-CROWN-6

Fig.172A



CRYPTAND [2.2.2]

Fig.172B



CRYPTAND [2.1.1]

Fig.173A

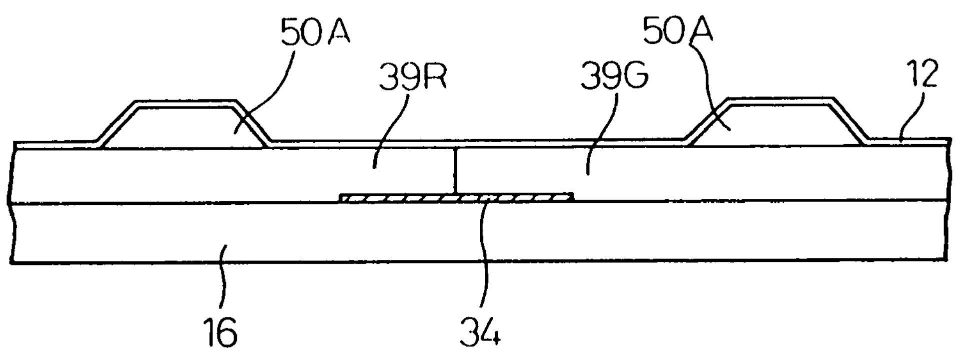


Fig.173B

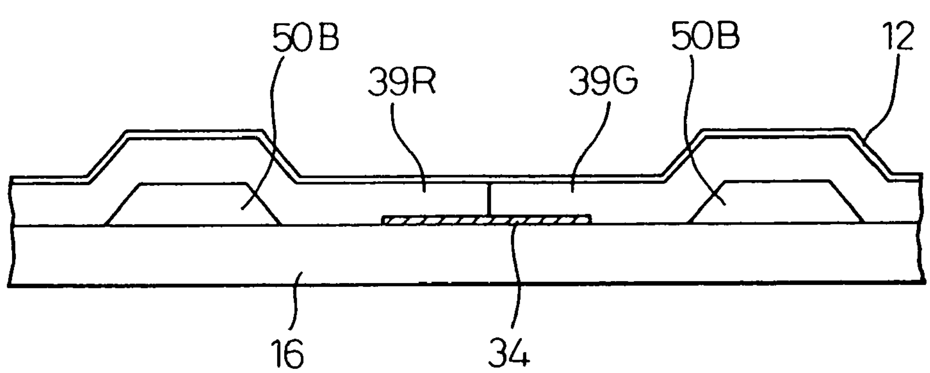


Fig.174

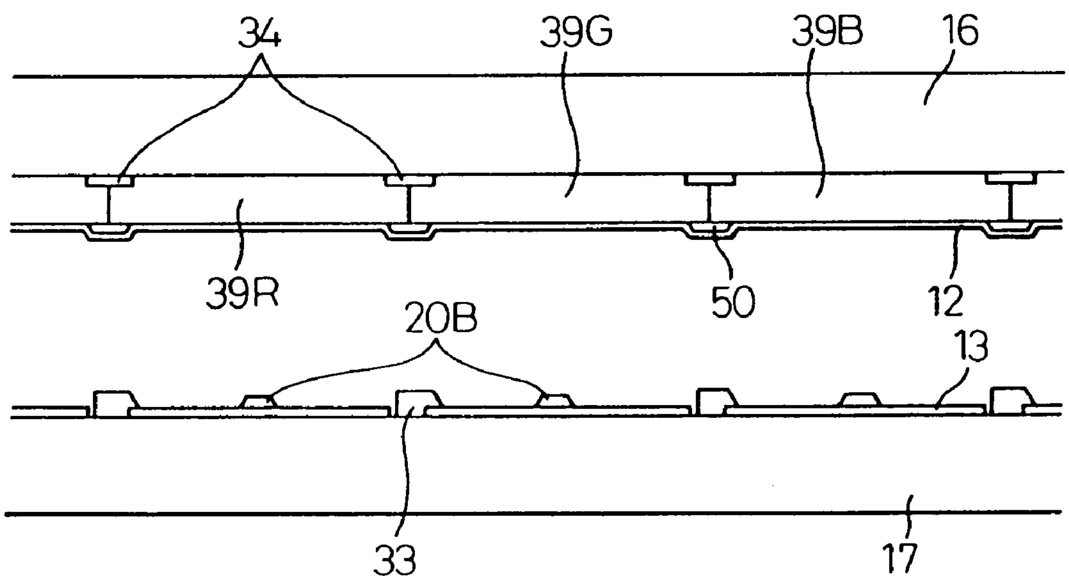


Fig.175A

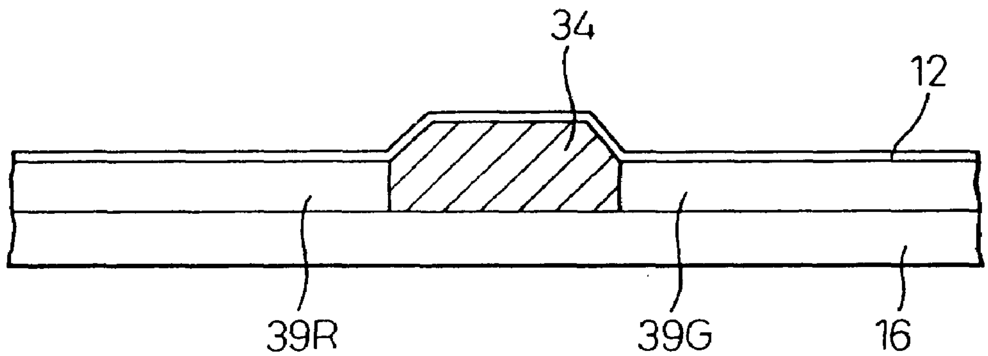


Fig.175B

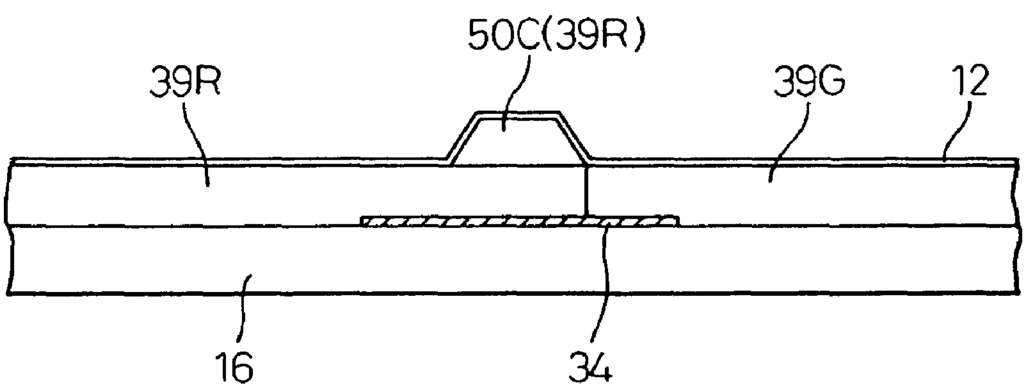


Fig.176A

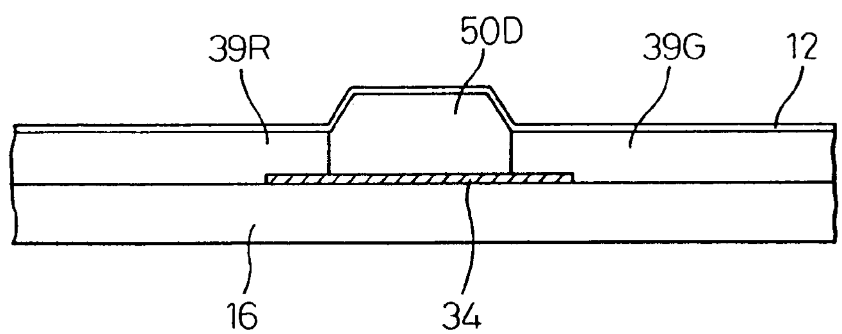


Fig.176B

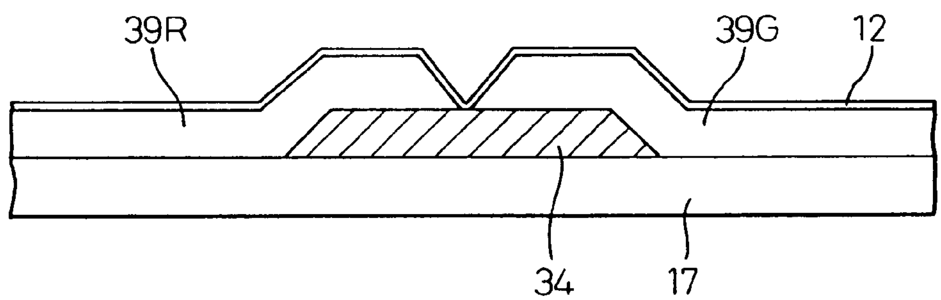


Fig.177A

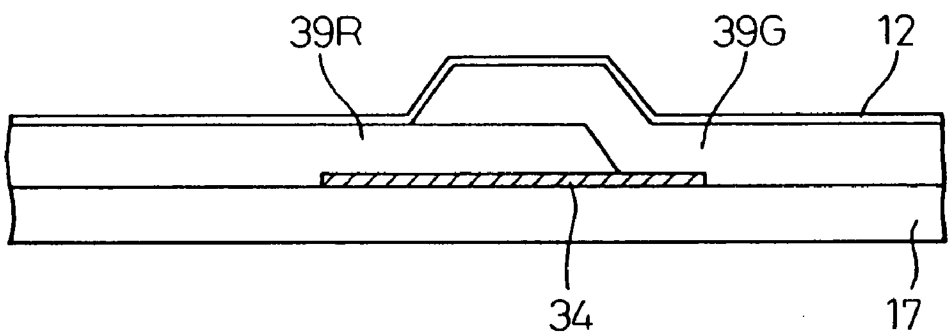


Fig.177B

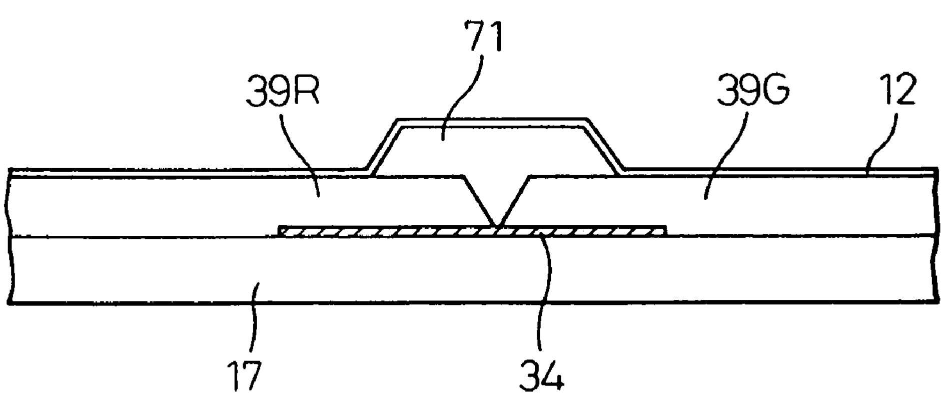


Fig.178

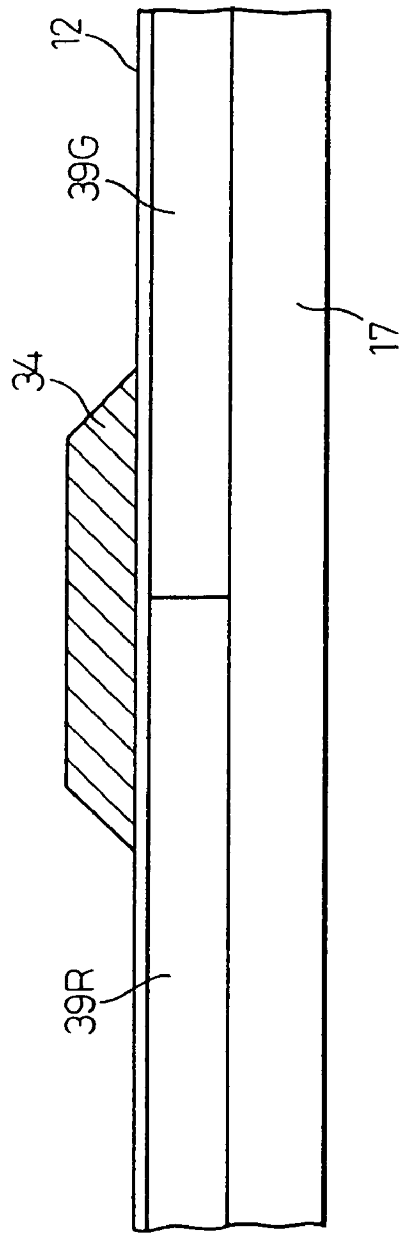


Fig.179A

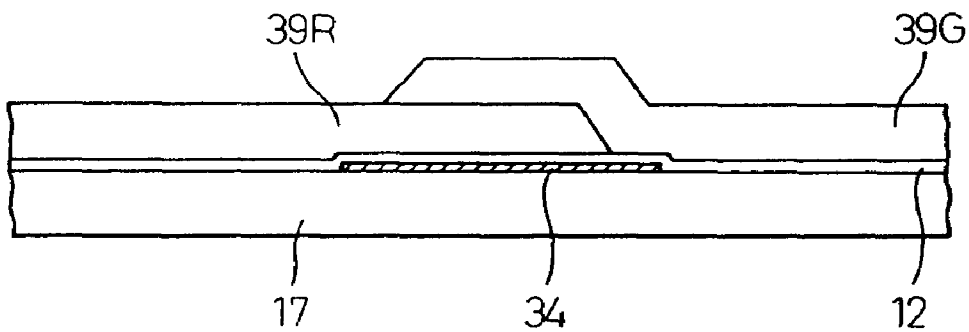


Fig.179B

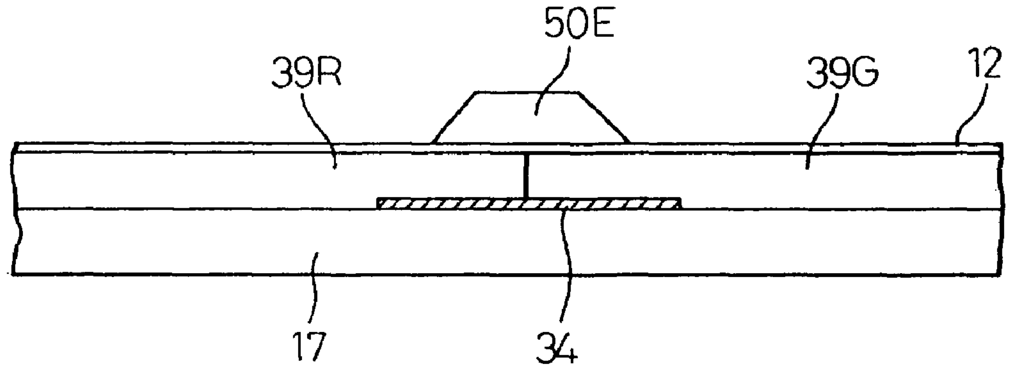


Fig.180A

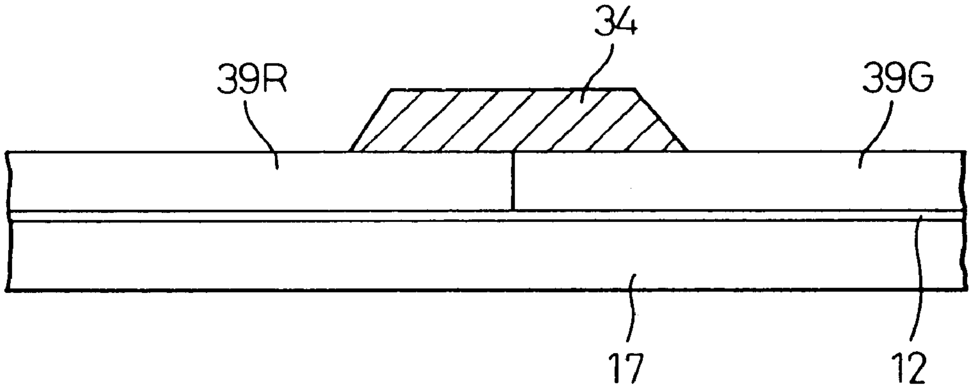


Fig.180B

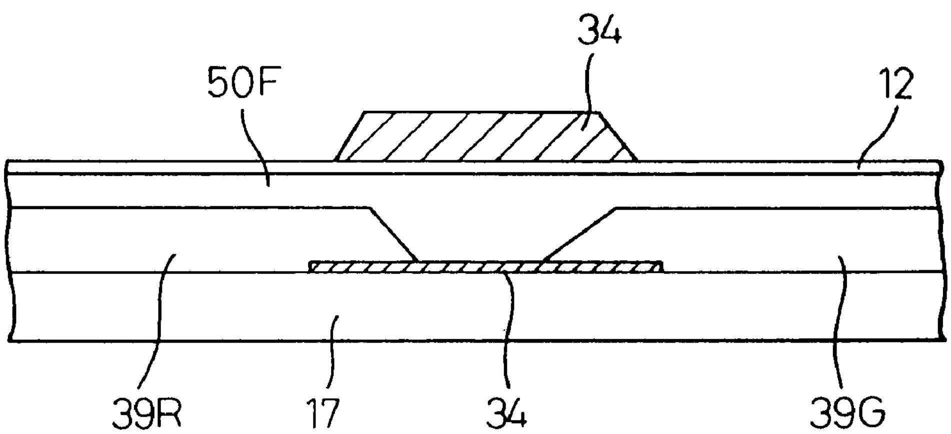


Fig.181A

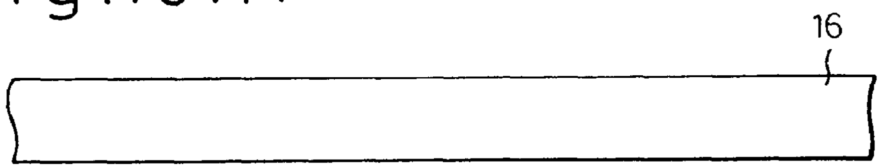


Fig.181B

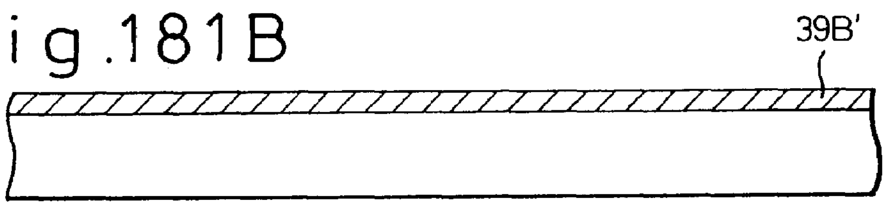


Fig.181C

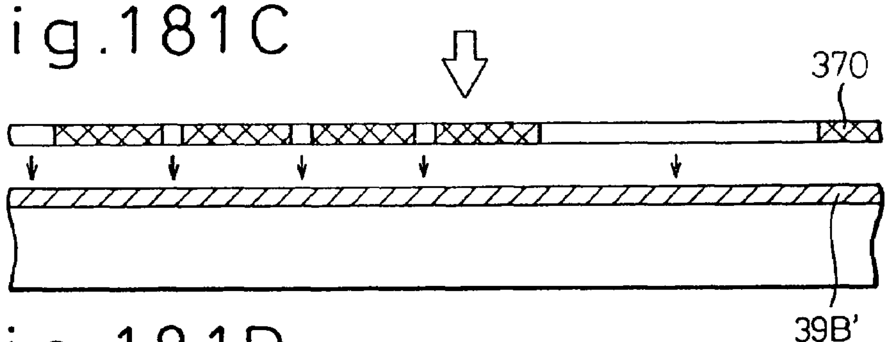


Fig.181D

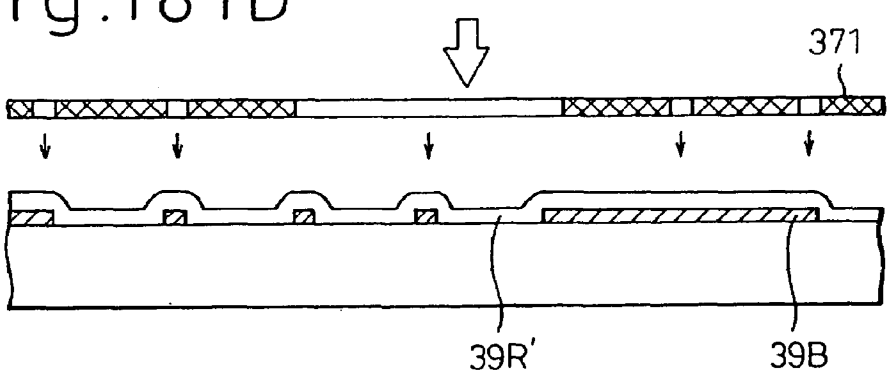


Fig.181E

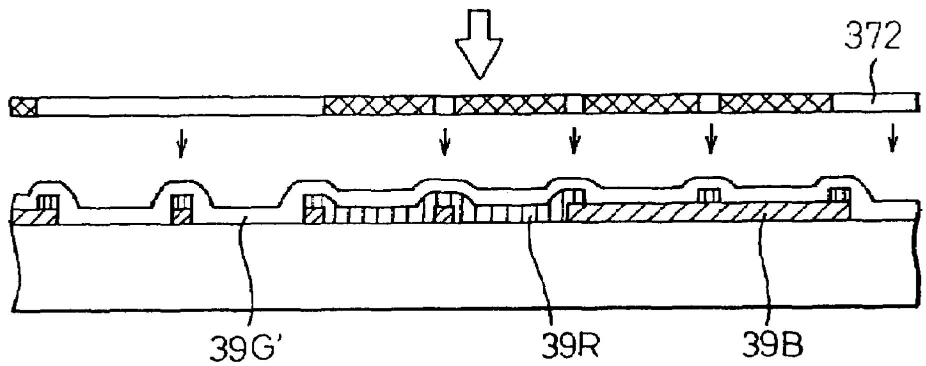


Fig.181F

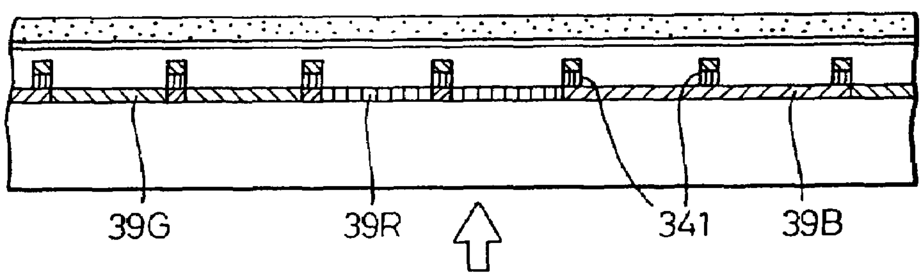


Fig.181G

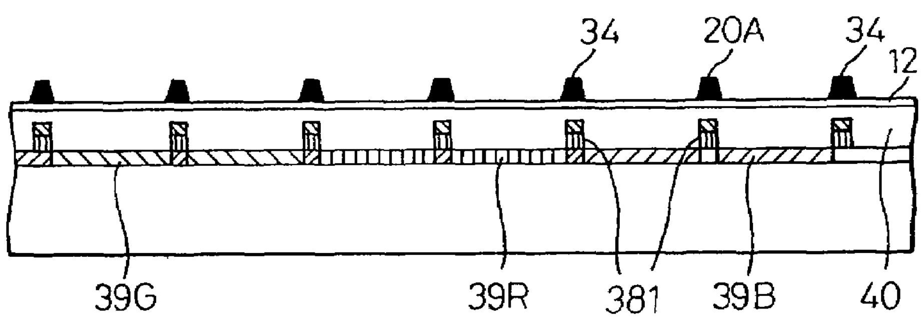


Fig.182

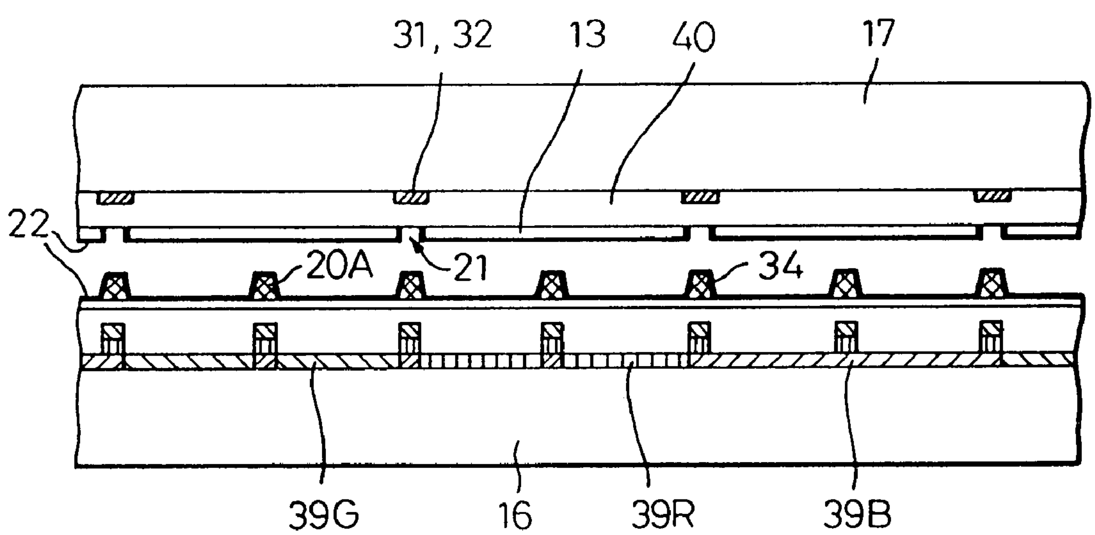


Fig.183A

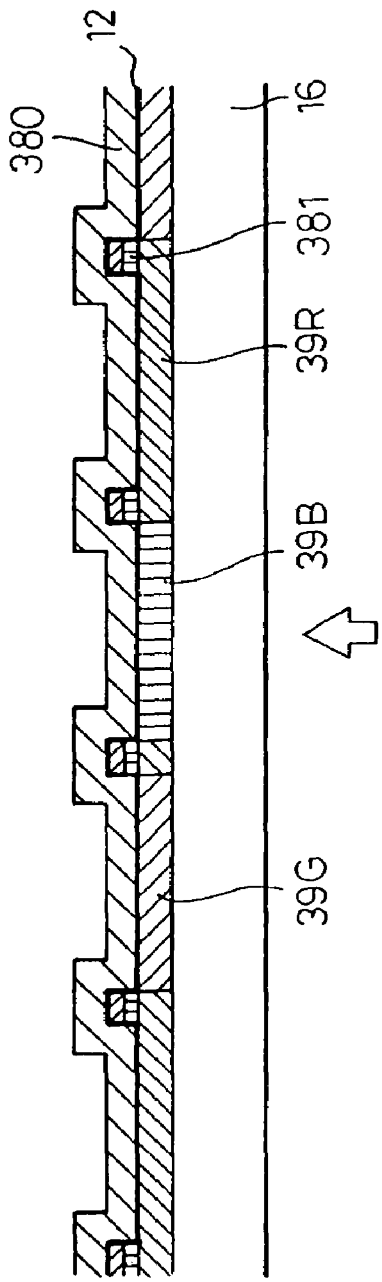
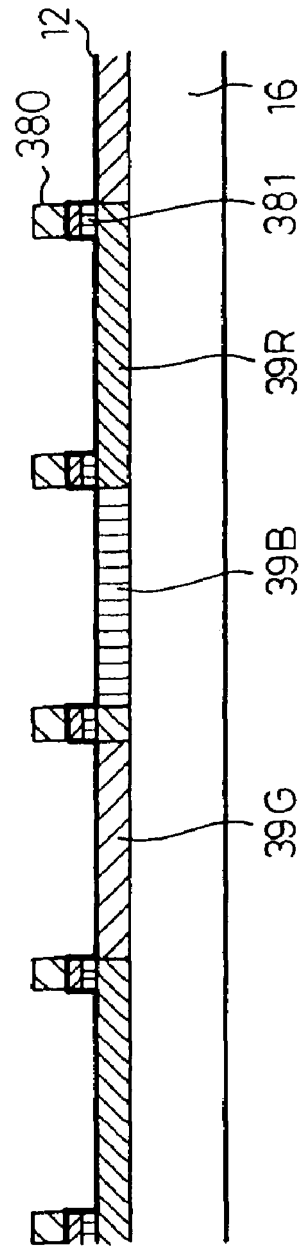


Fig.183B



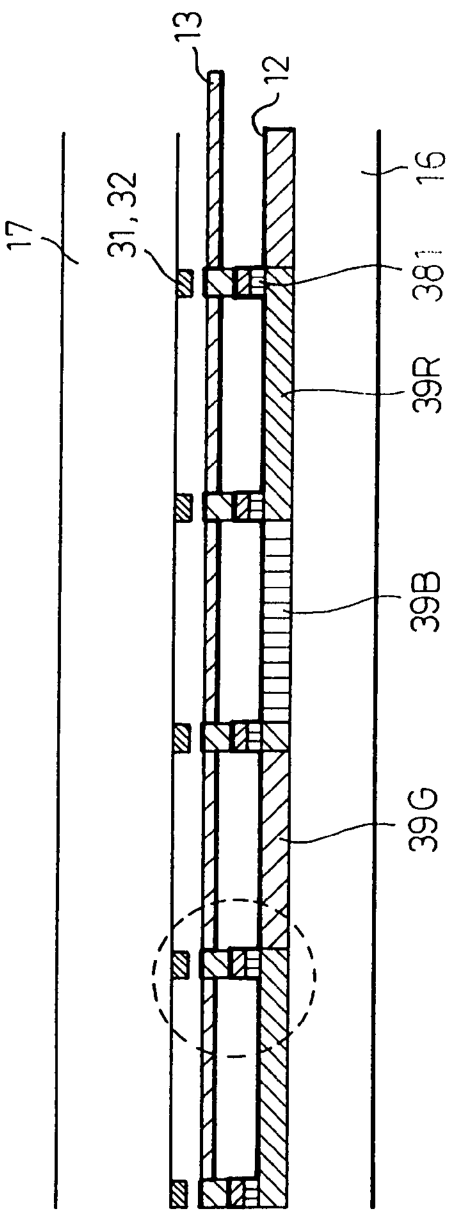


Fig.184A

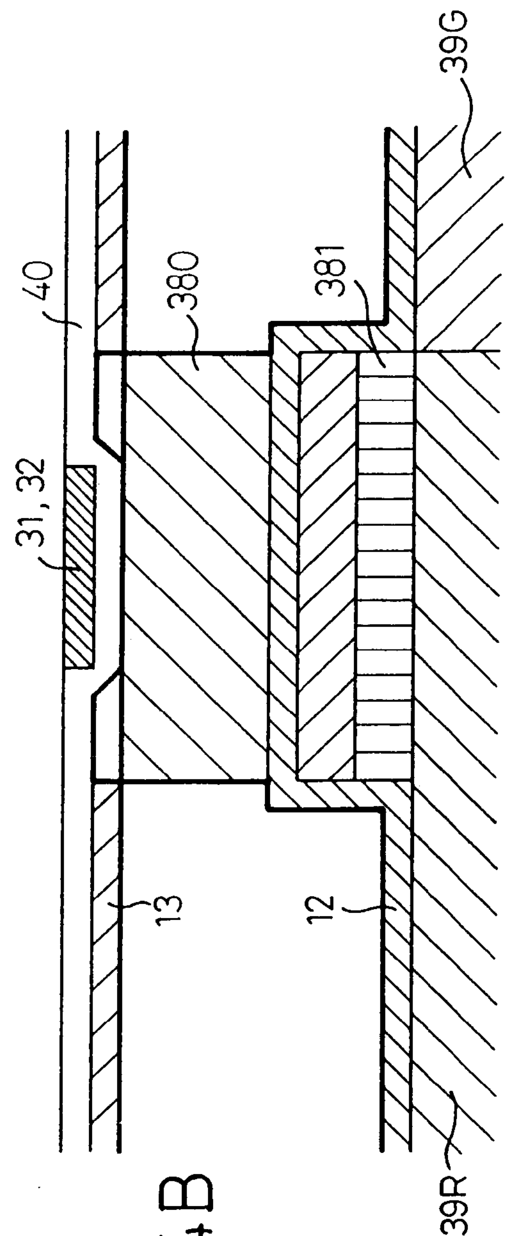


Fig.184B

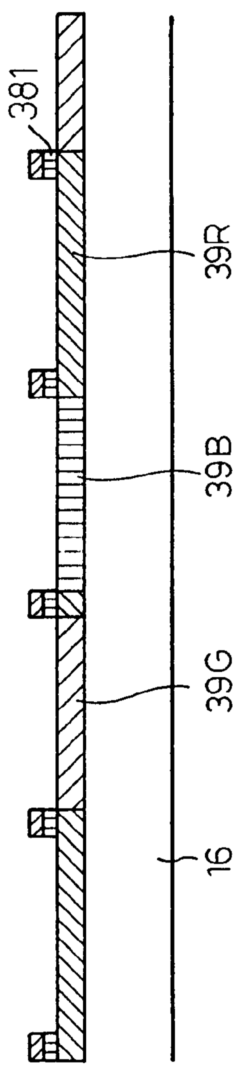


Fig.185A

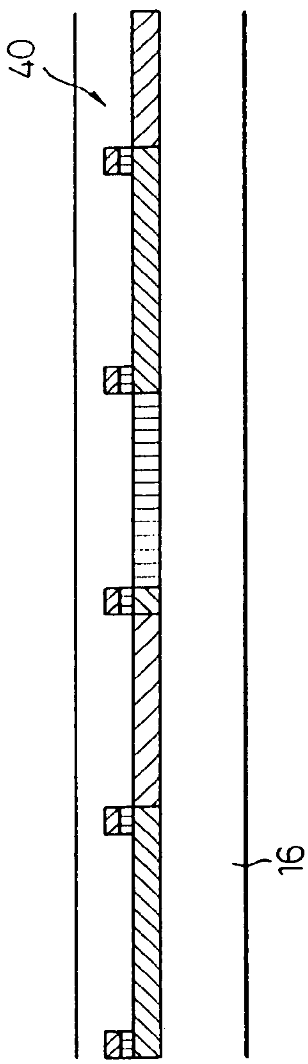


Fig.185B

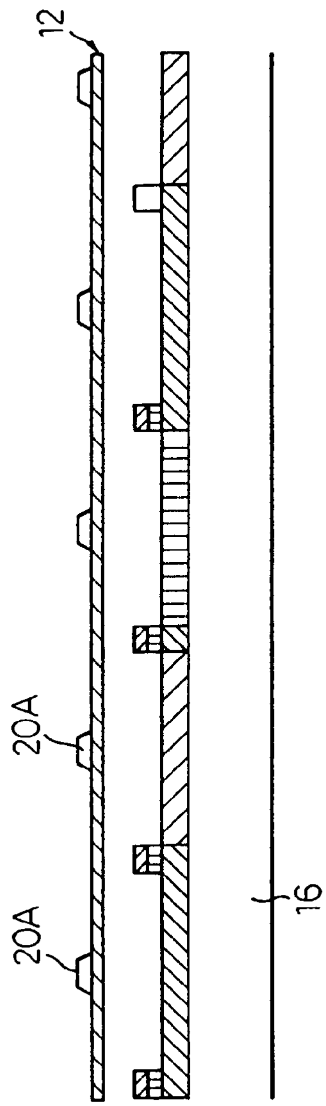


Fig.185C

Fig.186

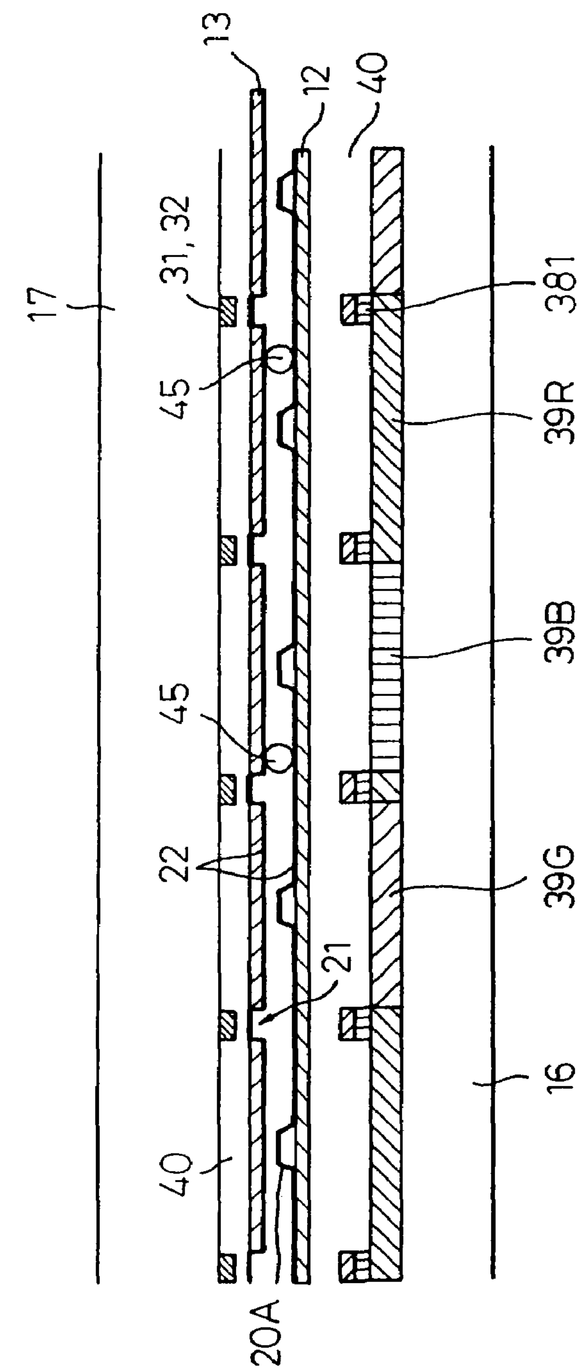
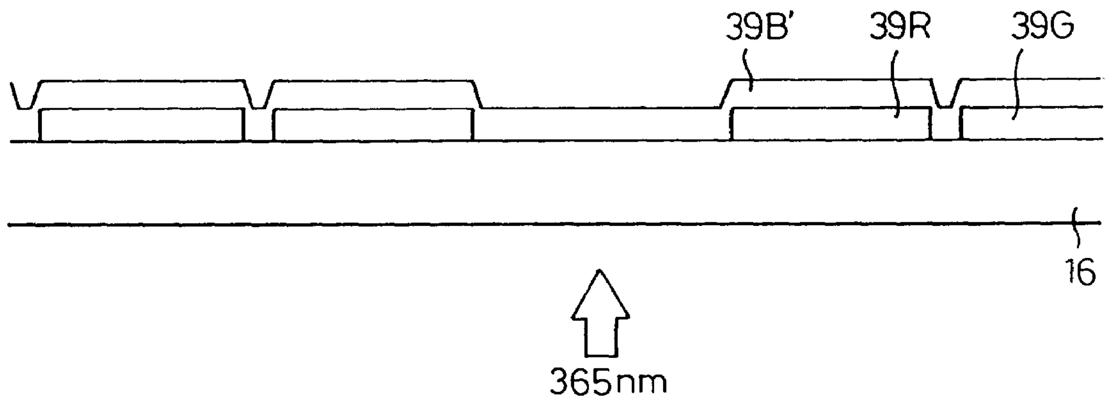


Fig.187



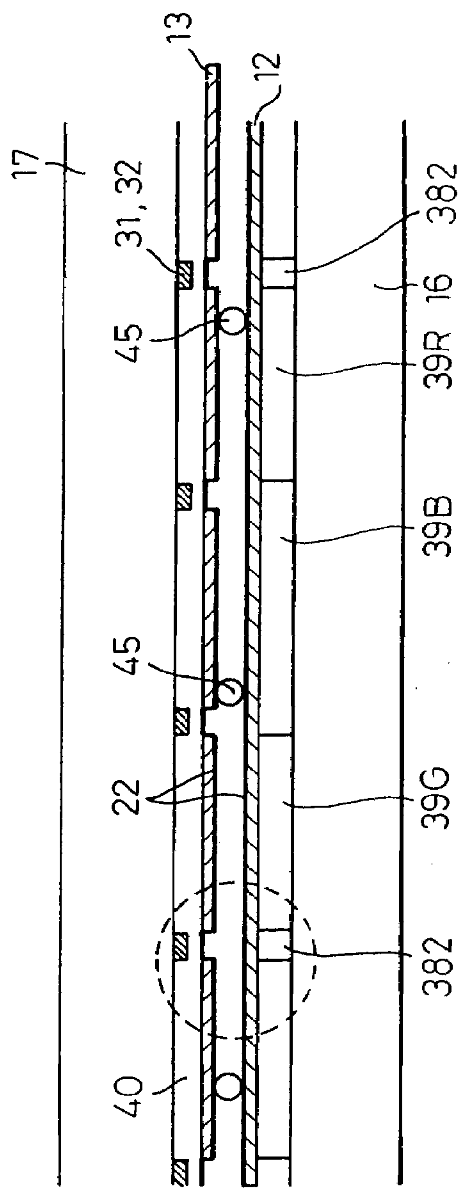


Fig.188A

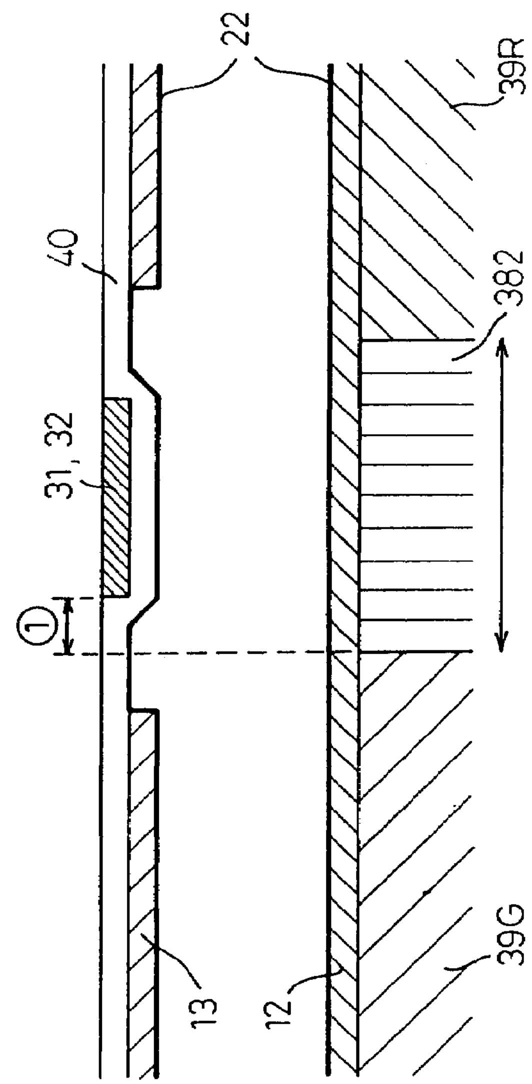


Fig.188B

Fig.189

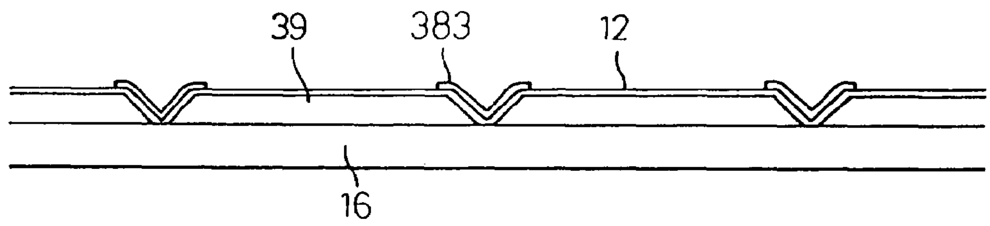


Fig.190A

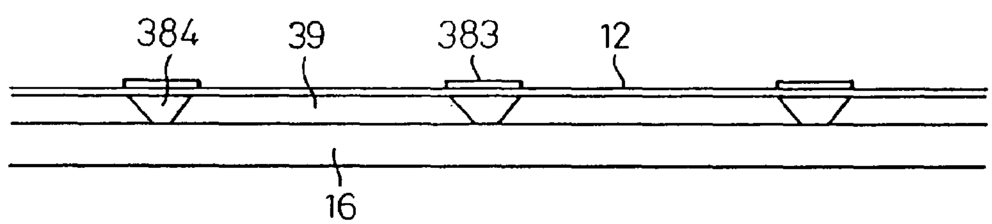


Fig.190B

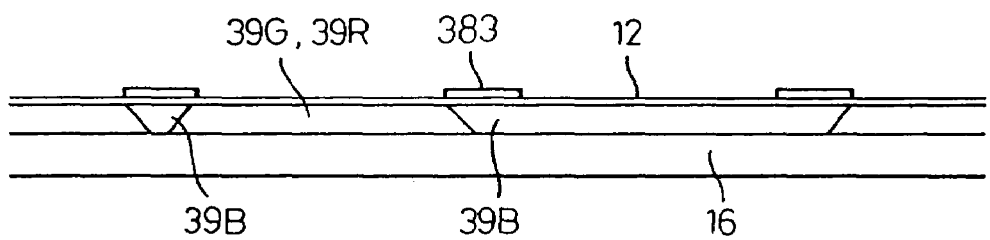


Fig.191

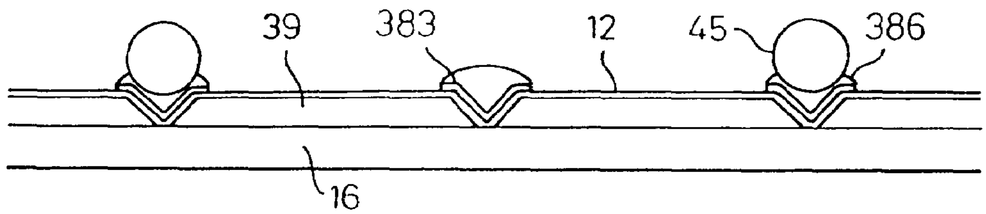


Fig.192

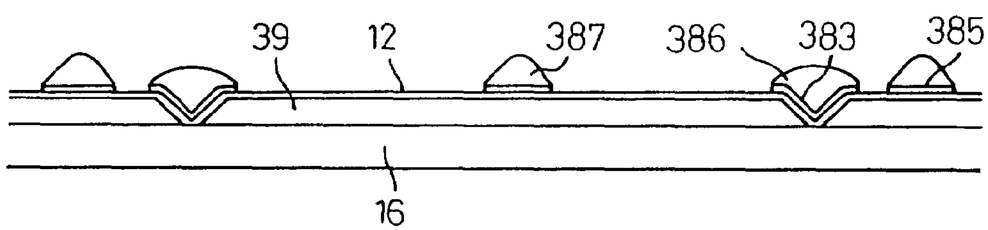


Fig.193

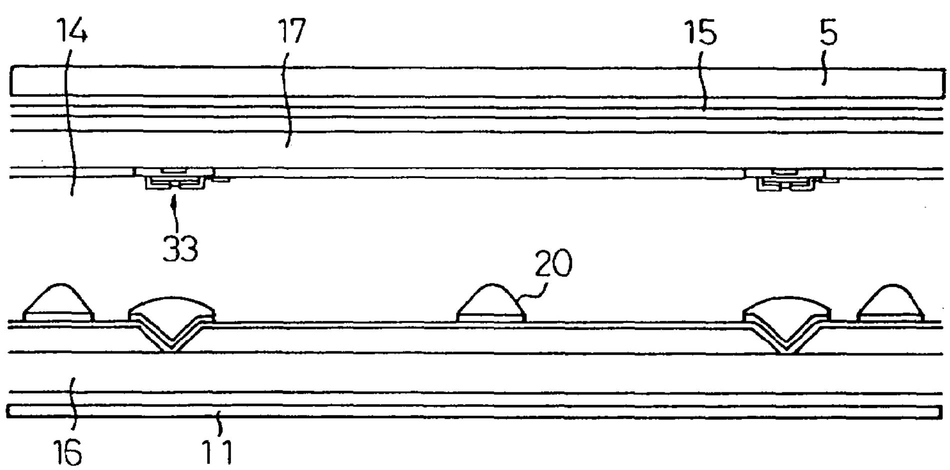


Fig.194

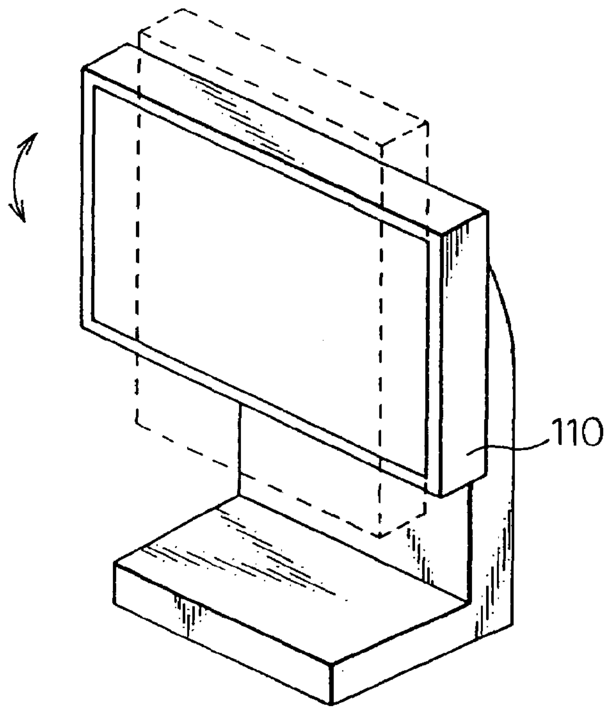


Fig.195

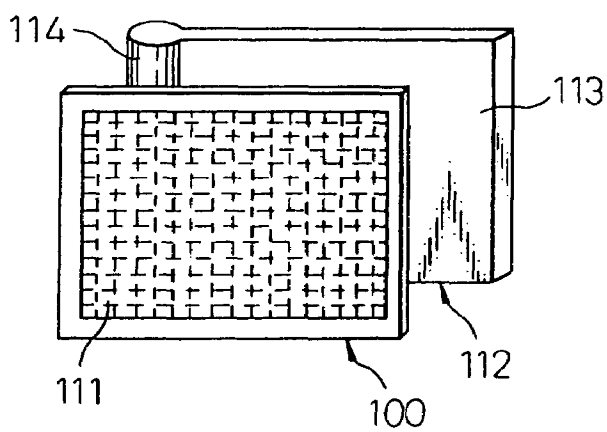


Fig.196A

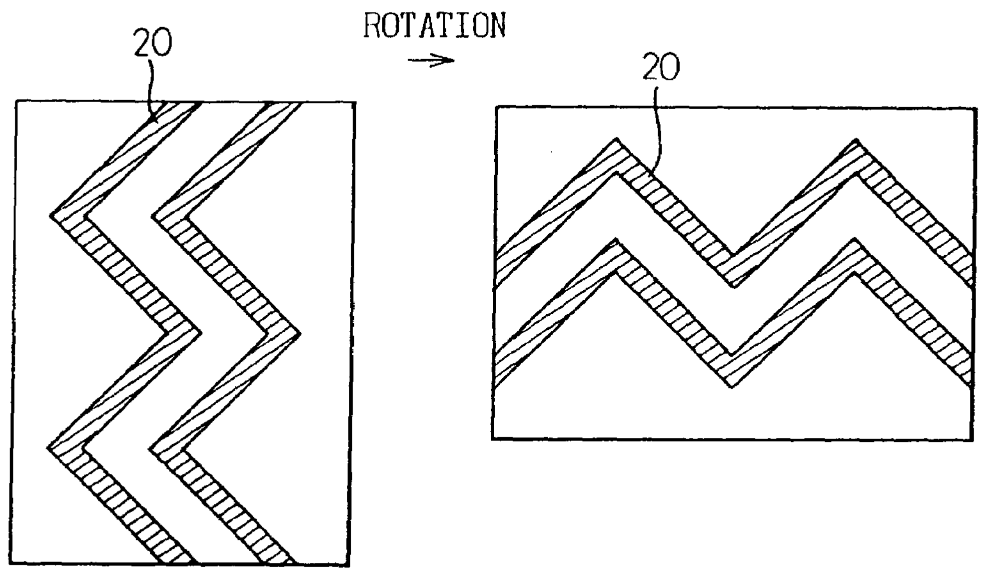


Fig.196B

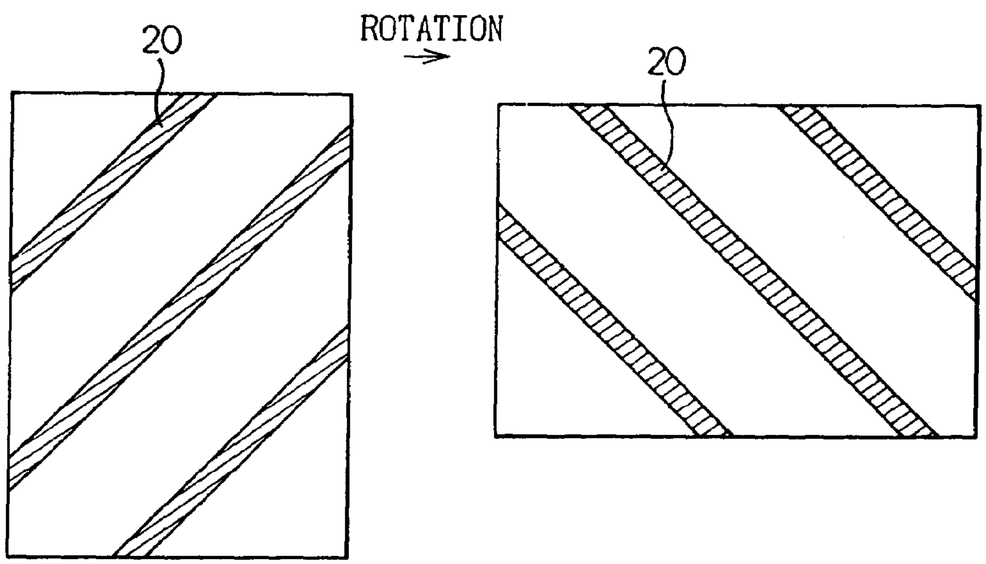


Fig.197

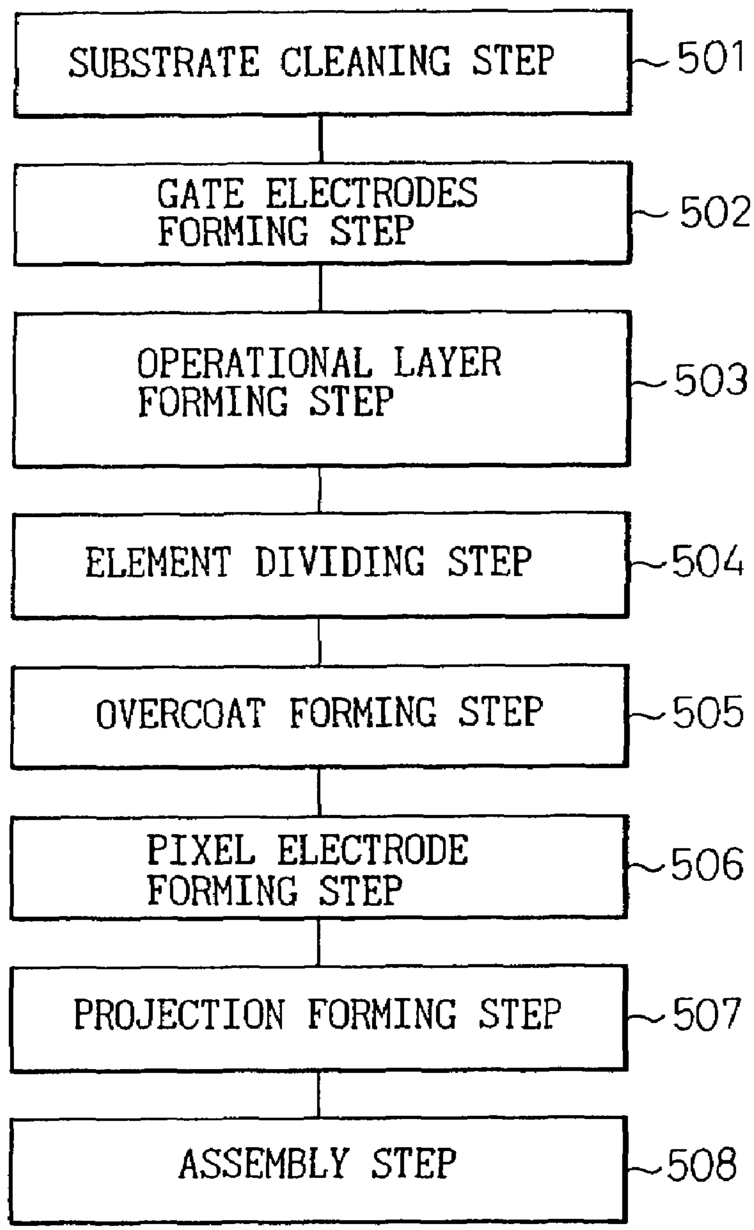

SUBSTRATE CLEANING STEP
501
GATE ELECTRODES FORMING STEP
502
OPERATIONAL LAYER FORMING STEP
503
ELEMENT DIVIDING STEP
504
OVERCOAT FORMING STEP
505
PIXEL ELECTRODE FORMING STEP
506
PROJECTION FORMING STEP
507
ASSEMBLY STEP
508

Fig.198

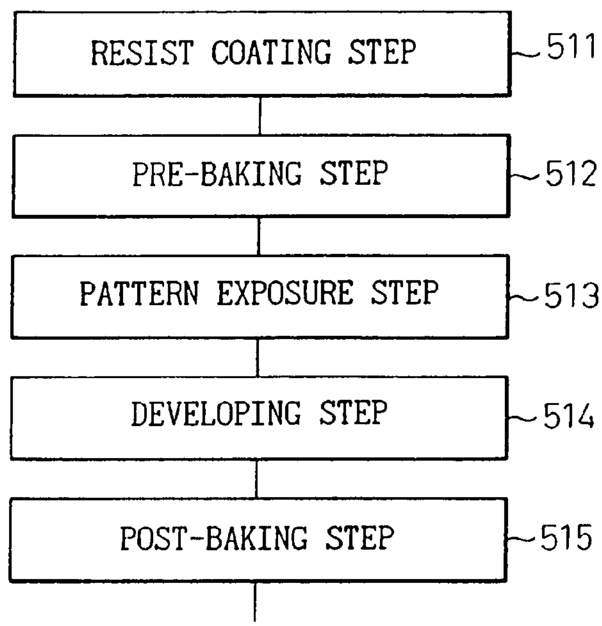


Fig.199

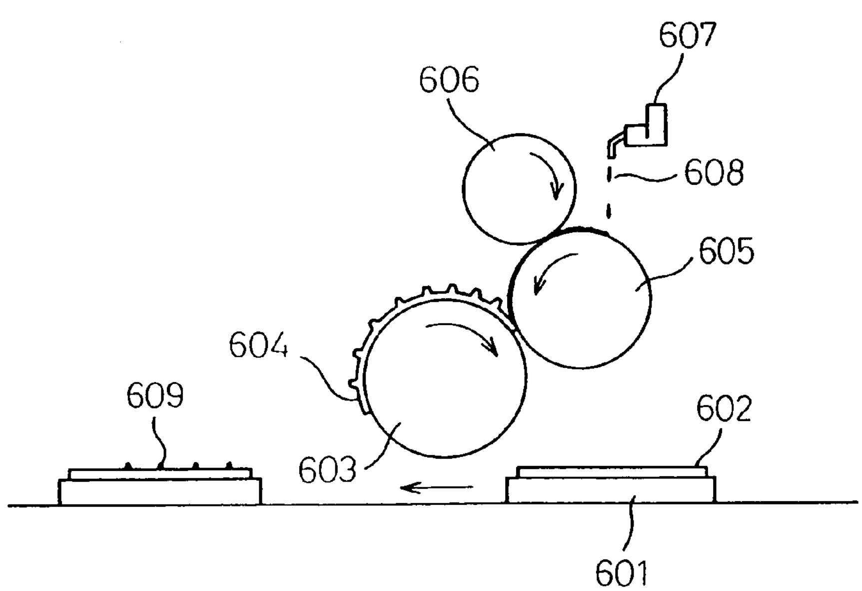


Fig. 200

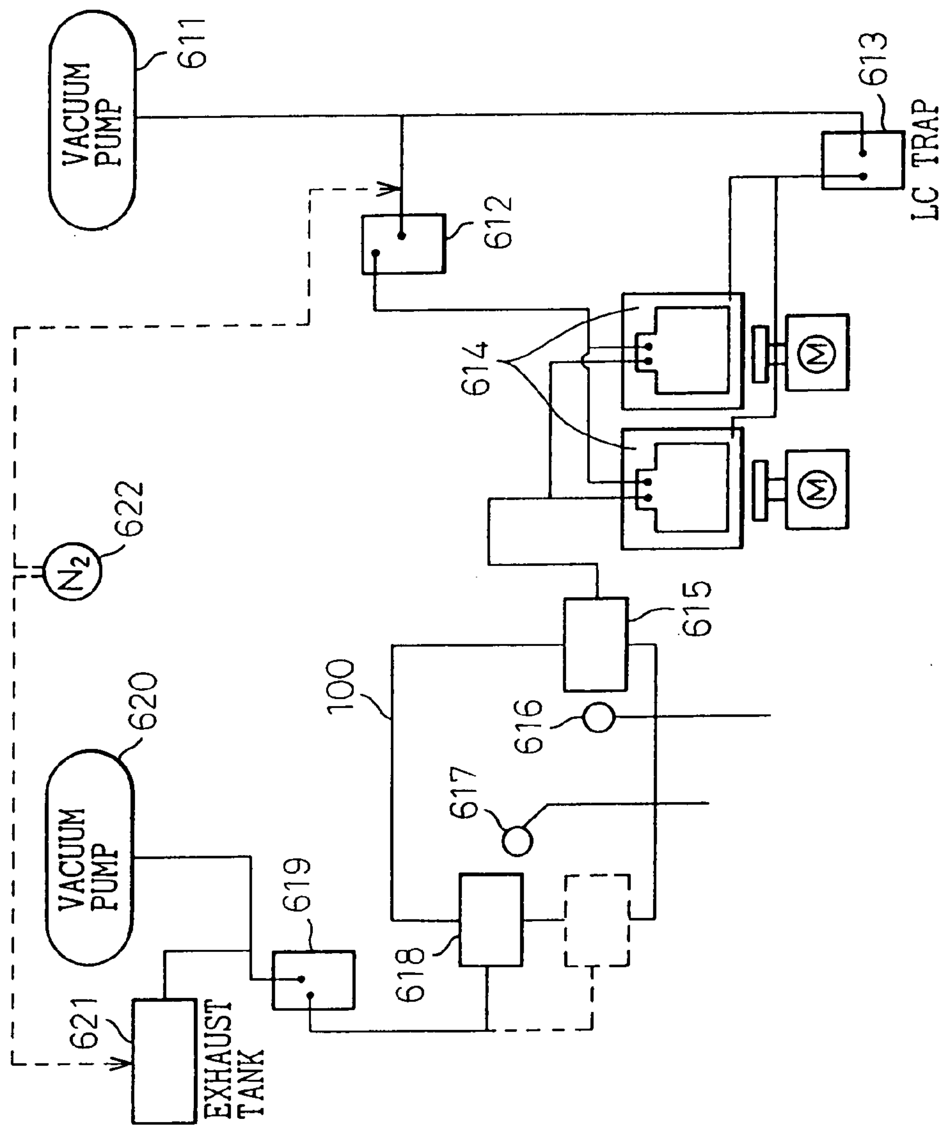

VACUUM PUMP
611
612
613
LC TRAP
614
M
M
615
100
616
617
VACUUM PUMP
620
N2
622
619
618
621
EXHAUST TANK

Fig. 201A

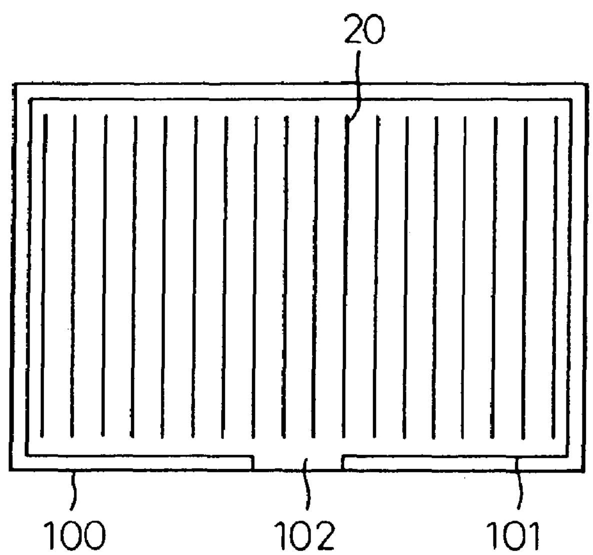


Fig. 201B

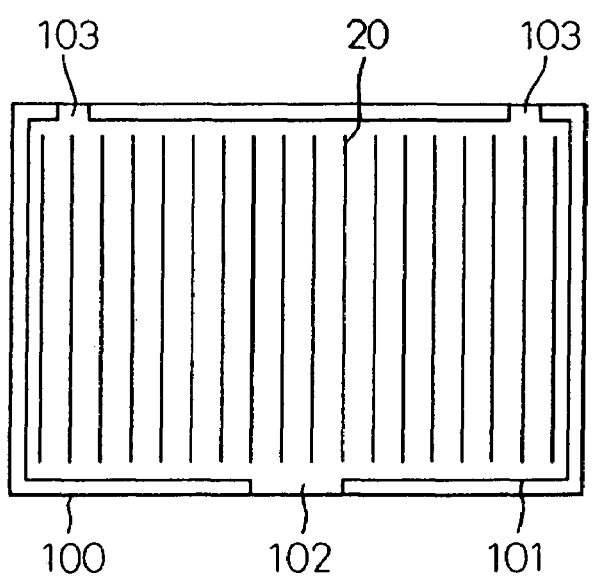


Fig. 202A

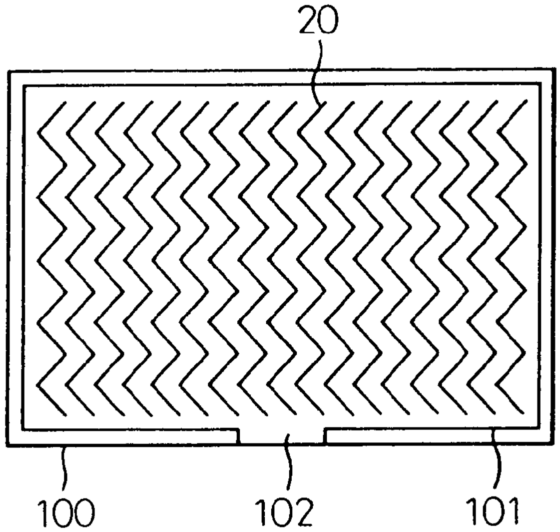


Fig. 202B

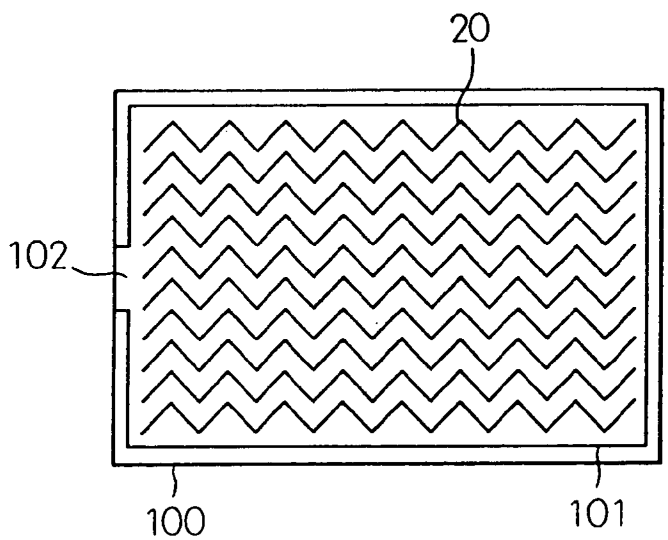


Fig.203A

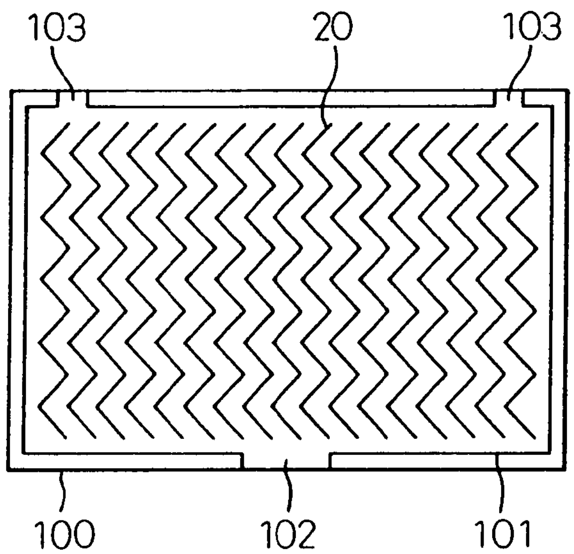


Fig.203B

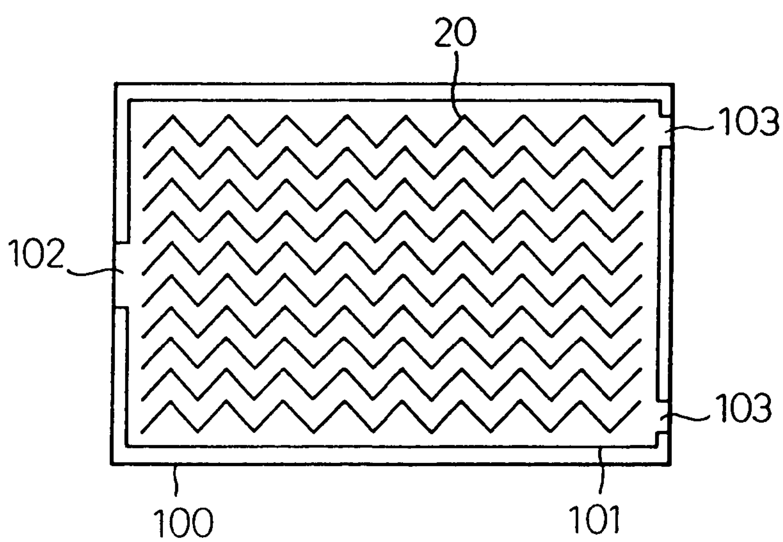


Fig. 204

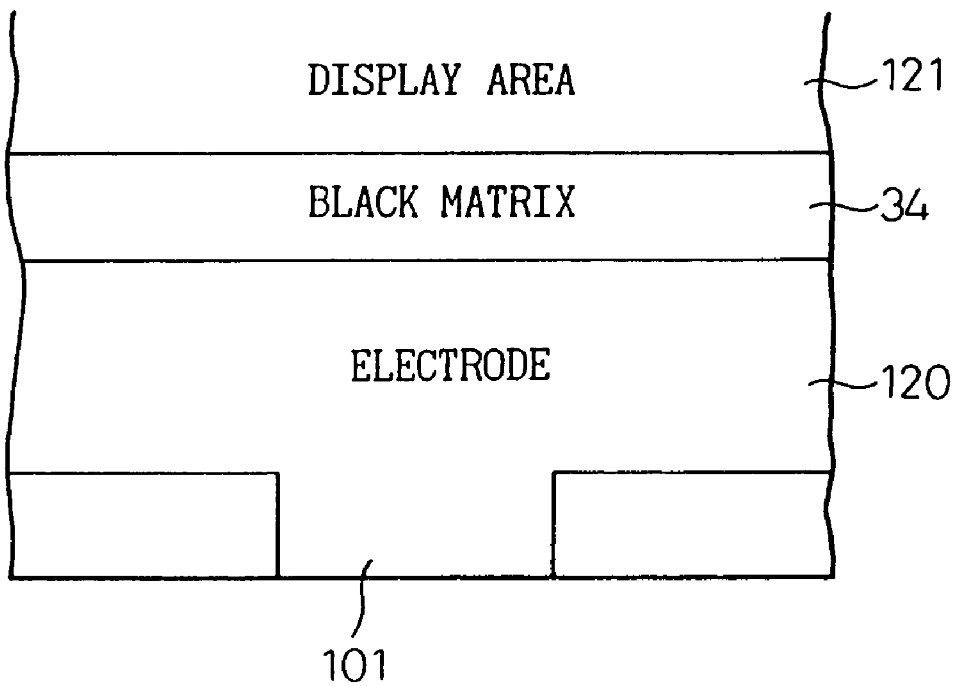


Fig.205A

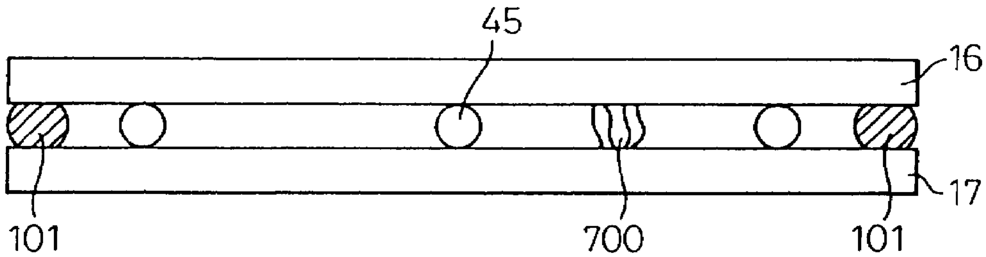


Fig.205B

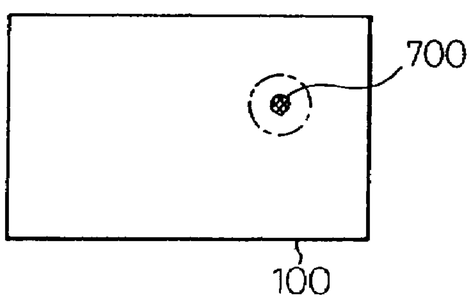


Fig.205C

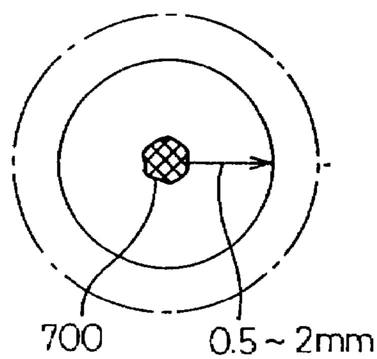


Fig.206

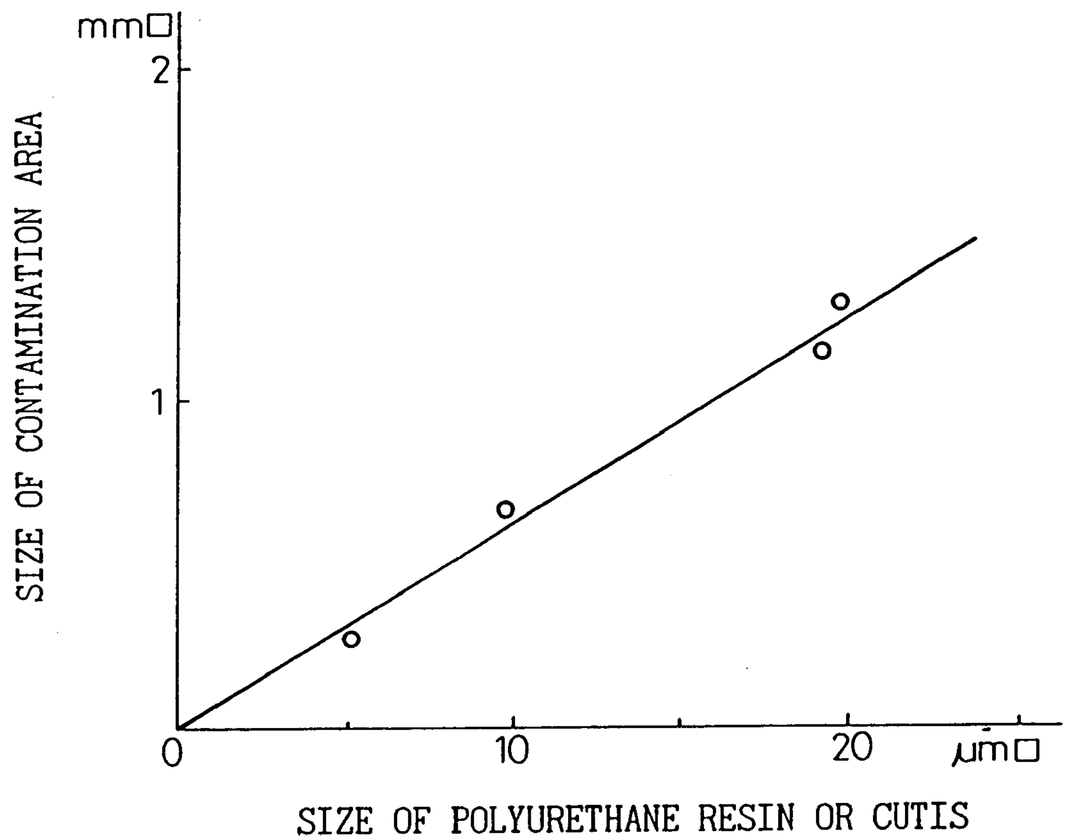
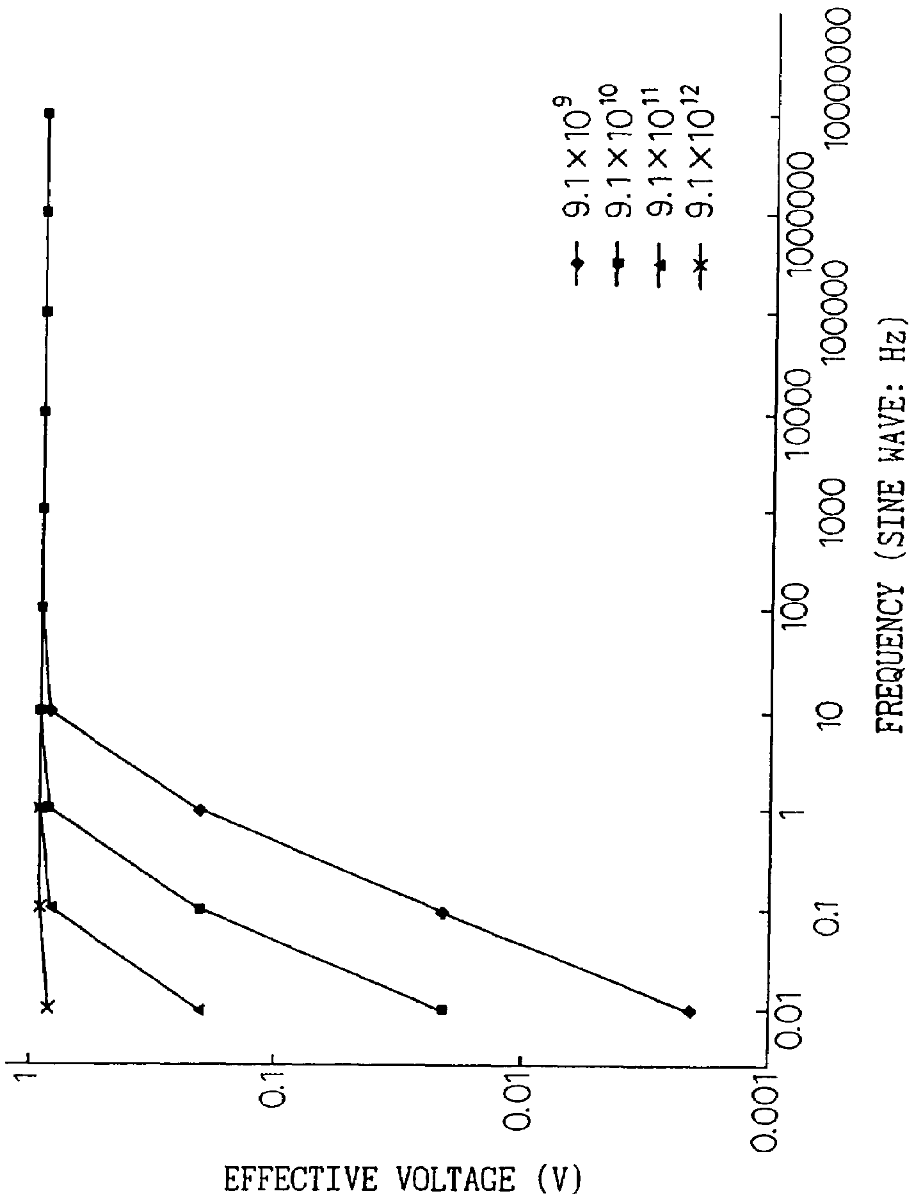
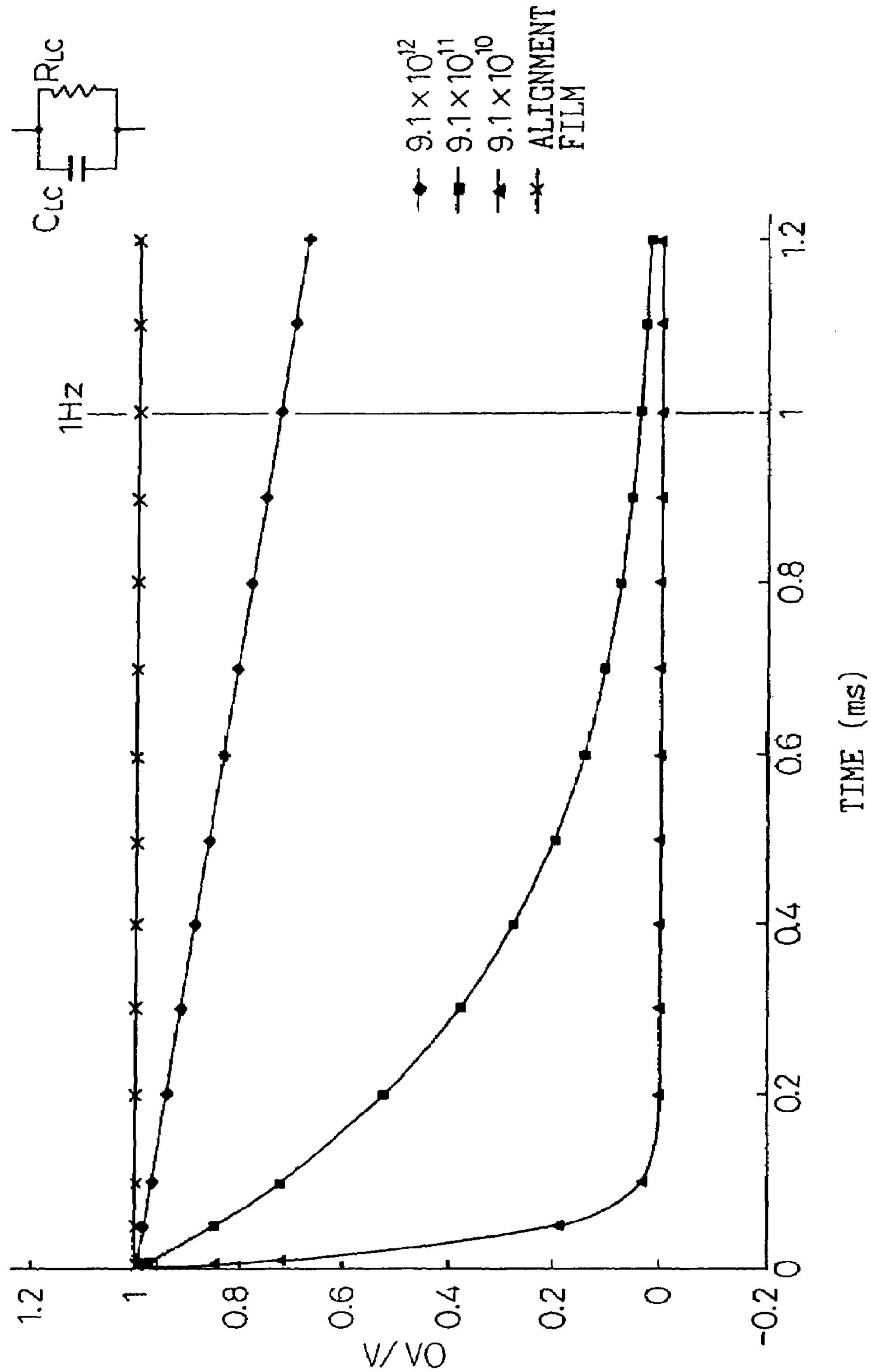

mm□
2
1
SIZE OF CONTAMINATION AREA
0
10
20
μm□
SIZE OF POLYURETHANE RESIN OR CUTIS

Fig. 207



EFFECTIVE VOLTAGE (V)
1
0.1
0.01
0.001
FREQUENCY (SINE WAVE: Hz)
0.01
0.1
1
10
100
1000
10000
100000
1000000
10000000
9.1×10^9
9.1×10^10
9.1×10^11
9.1×10^12

Fig.208



V
C_{LC}
R_{LC}
1Hz
9.1×10^{12}
9.1×10^{11}
9.1×10^{10}
ALIGNMENT FILM
V/VO
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0.2
0.4
0.6
0.8
1.2
TIME (ms)

Fig. 209

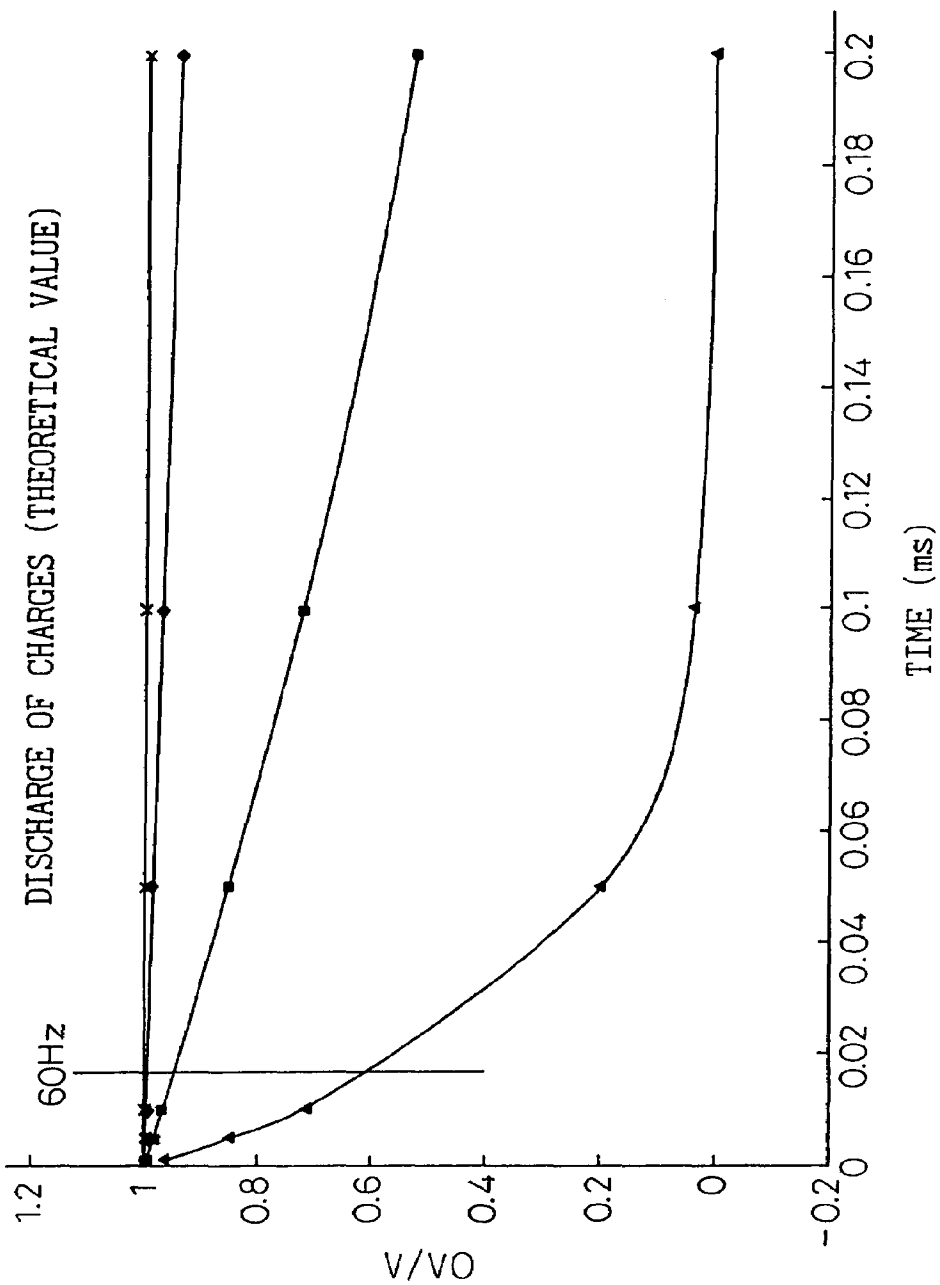

DISCHARGE OF CHARGES (THEORETICAL VALUE)
60Hz
V/VO
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
TIME (ms)

Fig.210

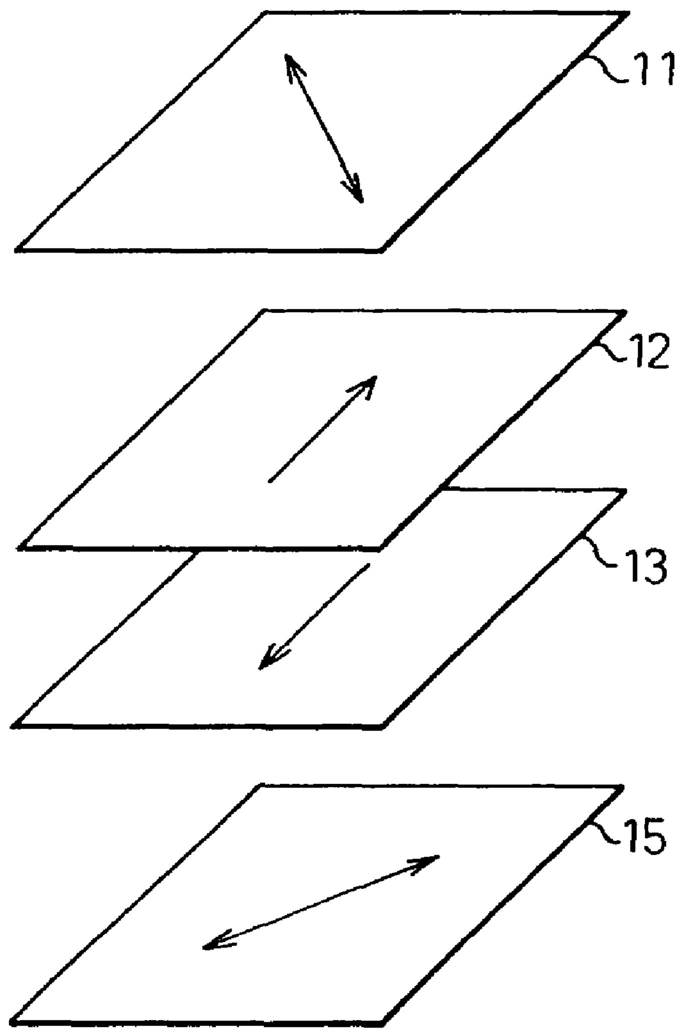


Fig.211

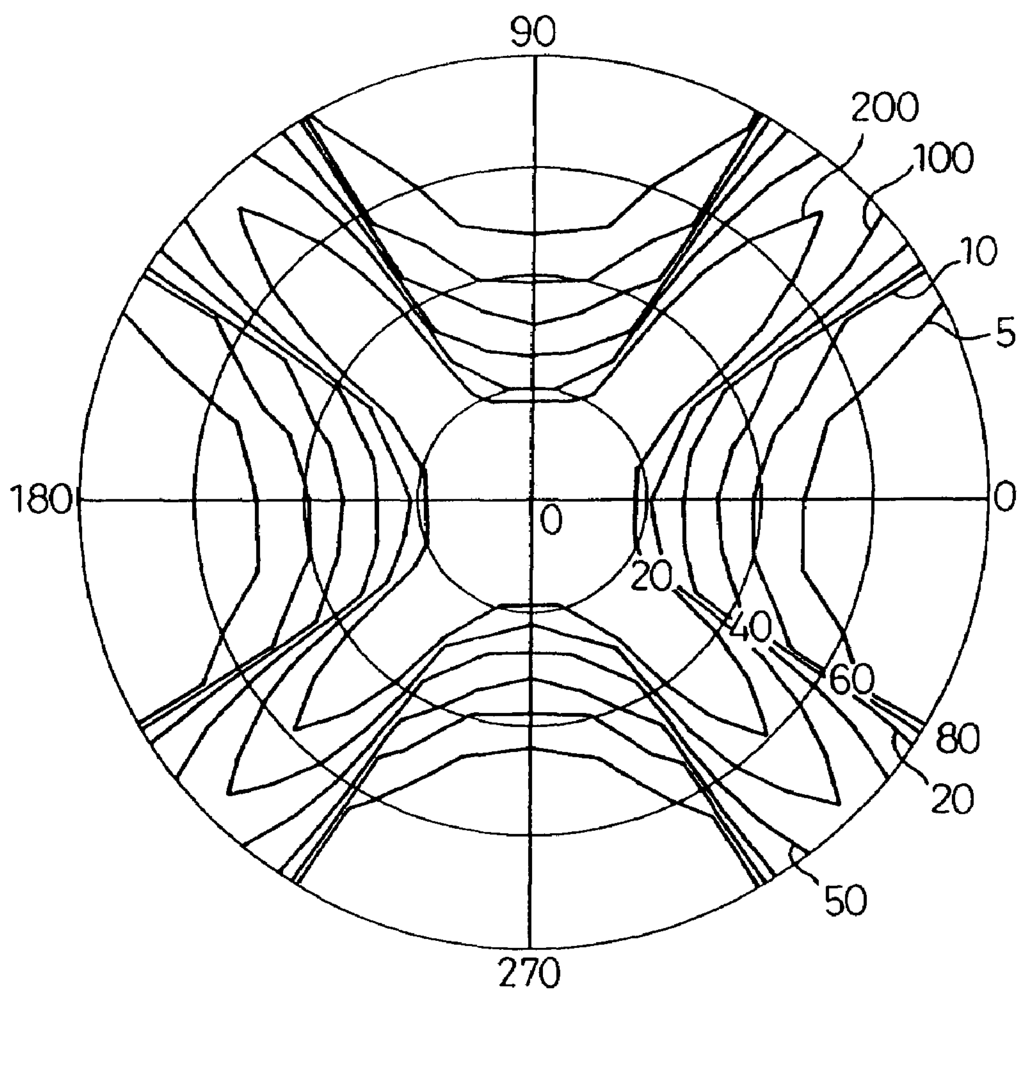


Fig.212

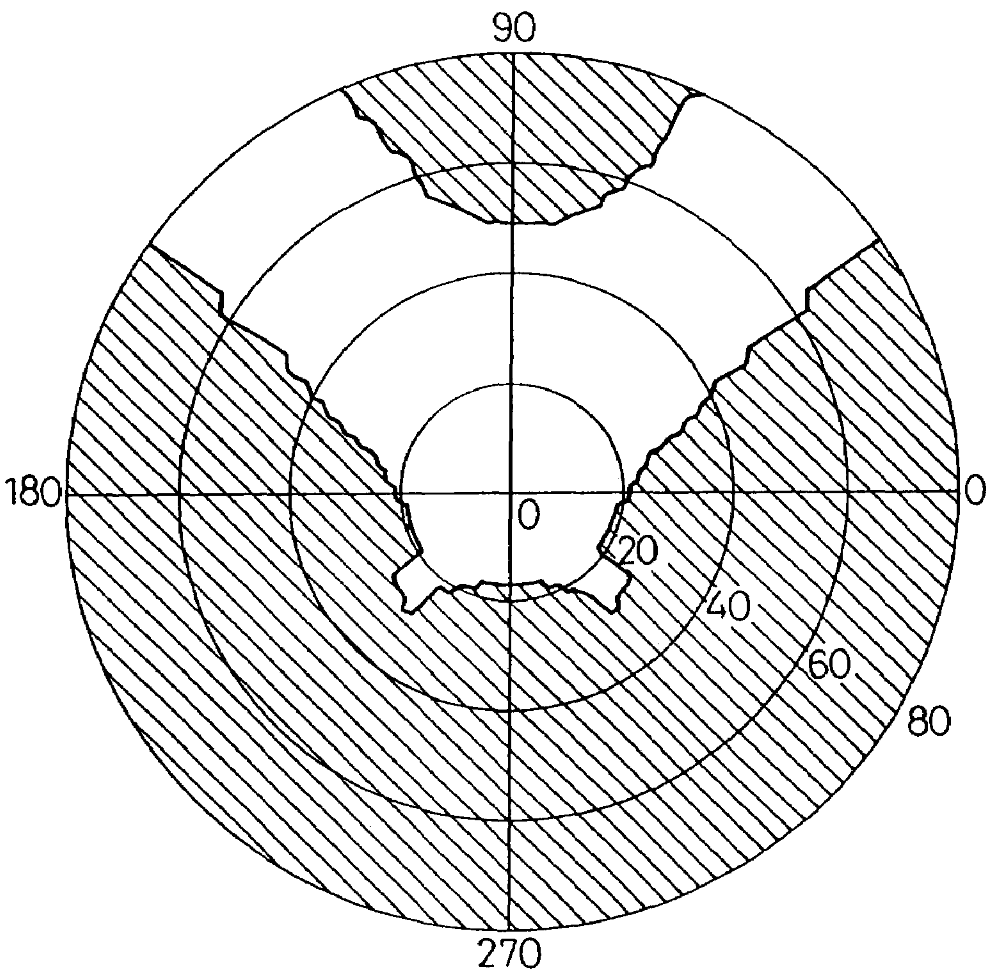


Fig.213

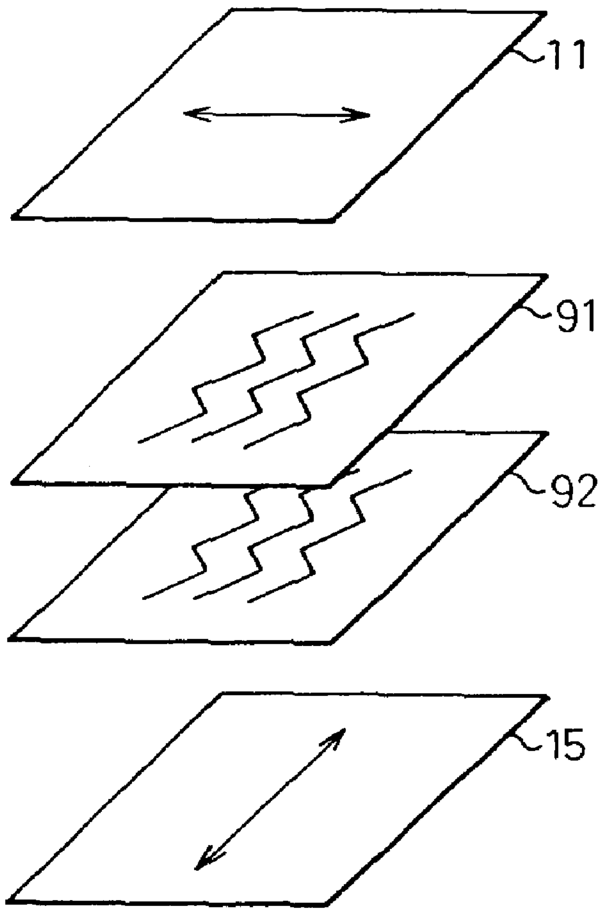


Fig. 214

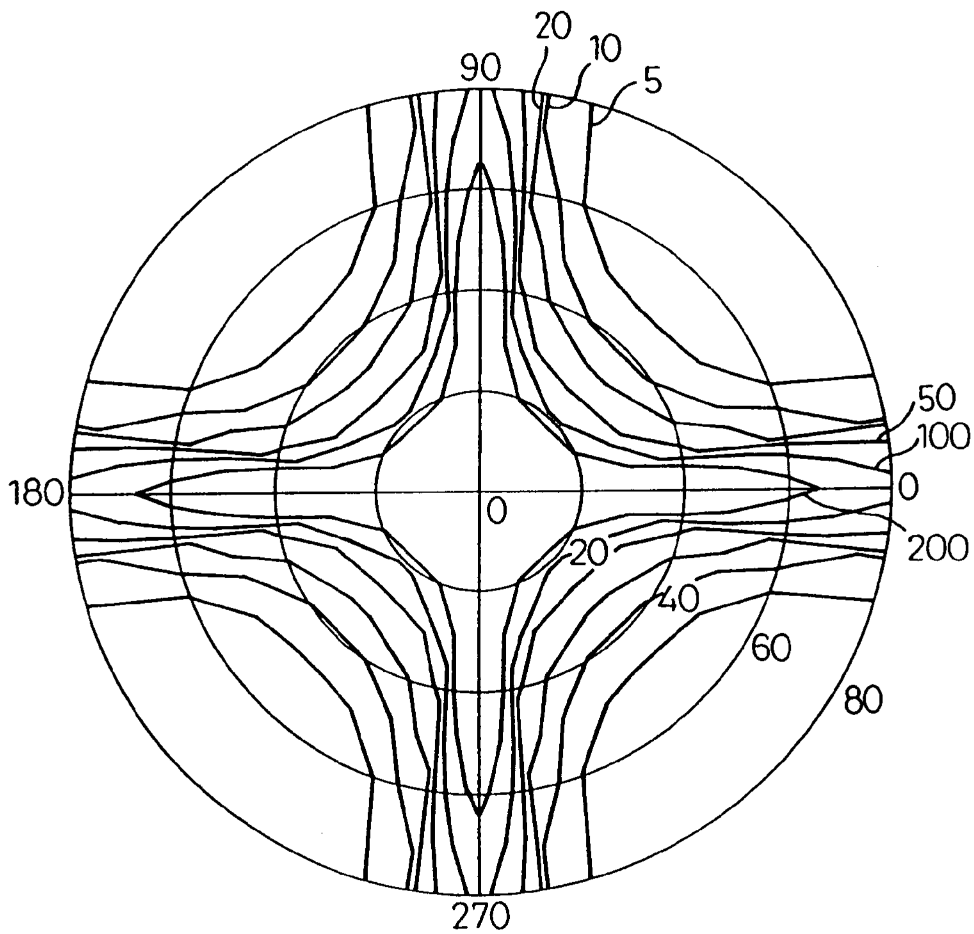


Fig.215

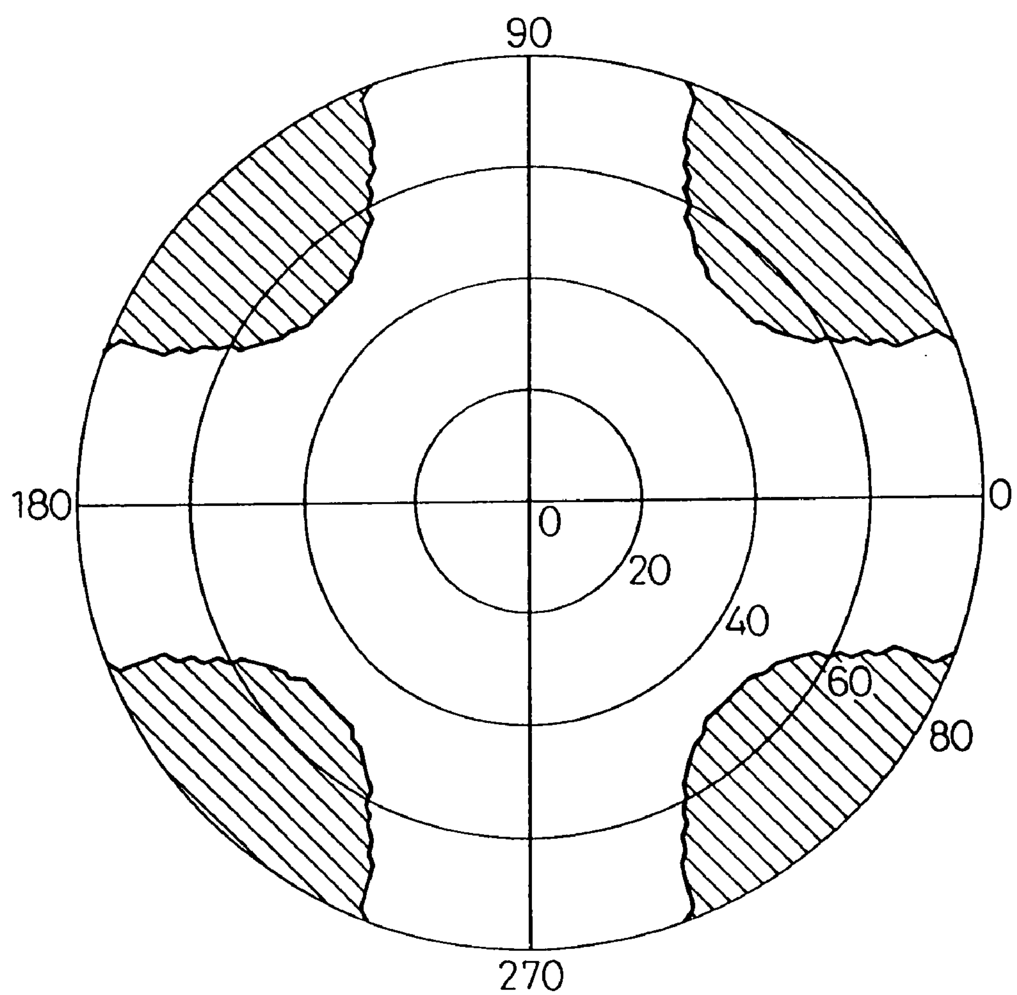
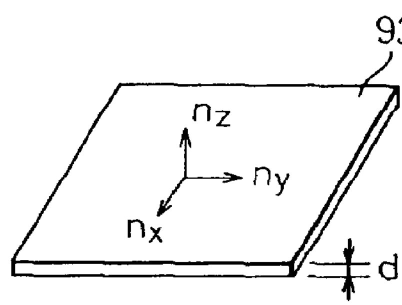


Fig.216



GENERAL CONDITION	$n_x,\ n_y \geq n_z$
POSITIVE UNIAXIAL FILM	$n_x > n_y = n_z$
NEGATIVE UNIAXIAL FILM	$n_x = n_y > n_z$
BIAXIAL FILM (A PHASE LAG AXIS IS X DIRECTION.)	$n_x > n_y > n_z$
RETARDATION IN INPLANE DIRECTIONS	$R = (n_x - n_y)d$
RETARDATION OF THICKNESS DIRECTION	$R = \left(\frac{n_x + n_y}{2} - n_z\right)d$

Fig. 217

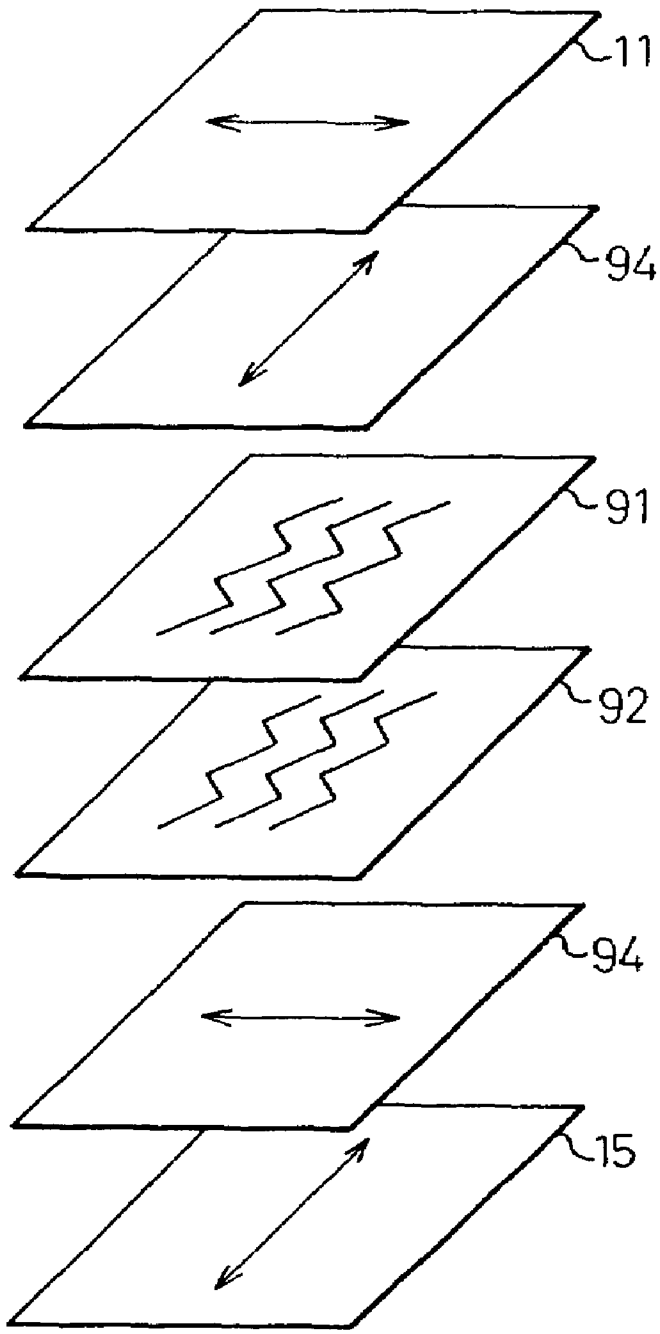


Fig.218

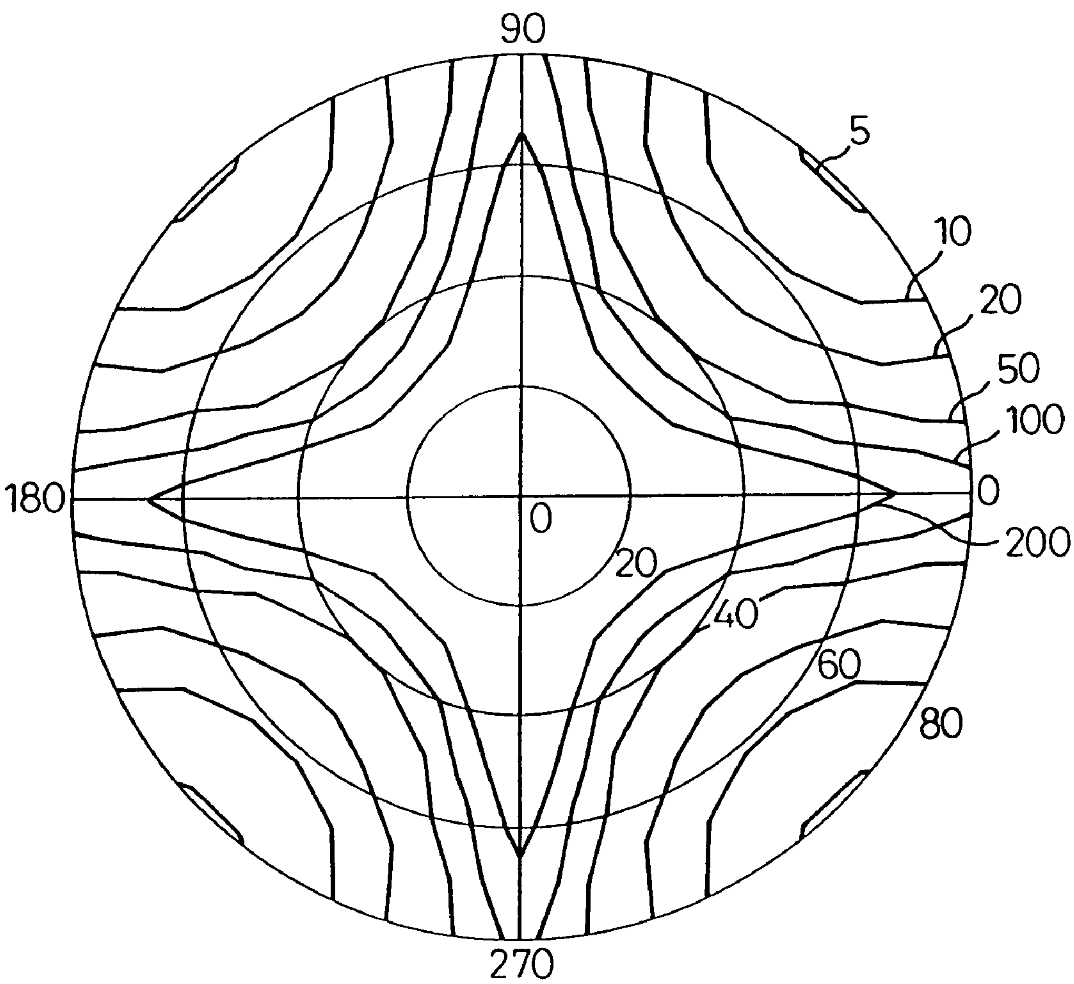


Fig.219

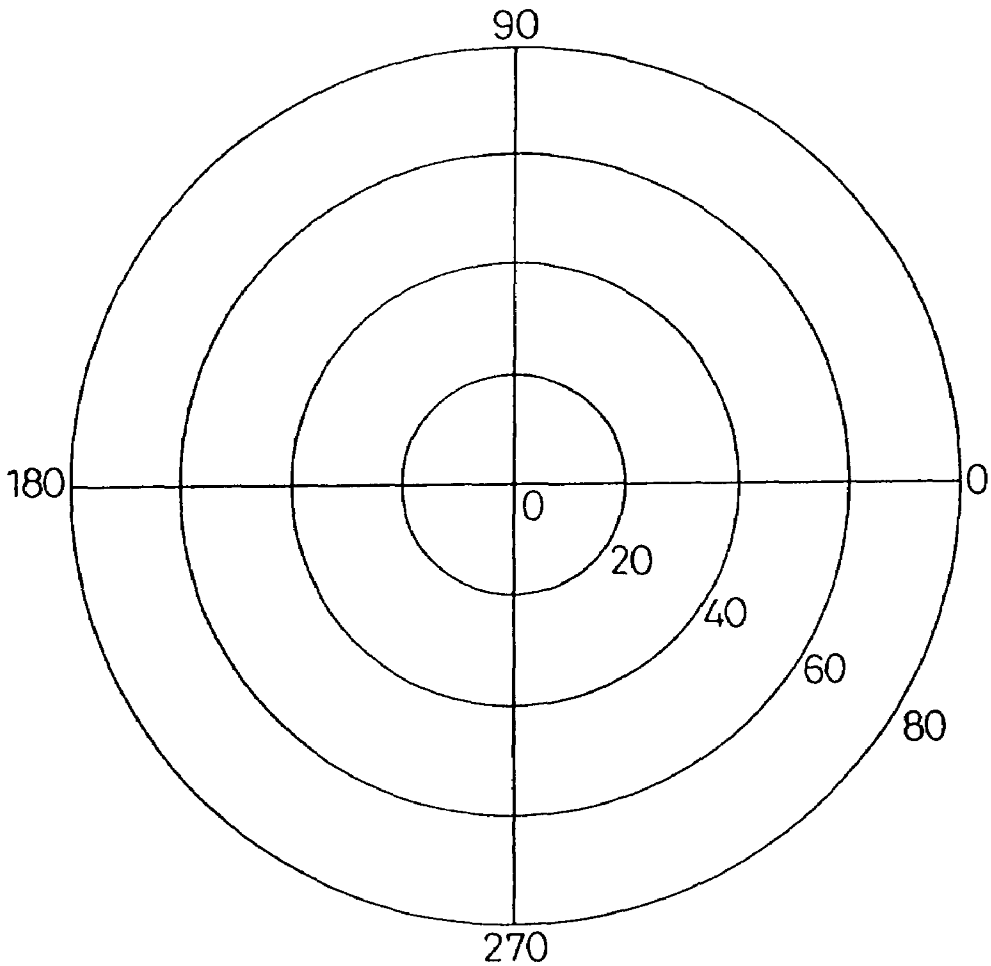


Fig. 220

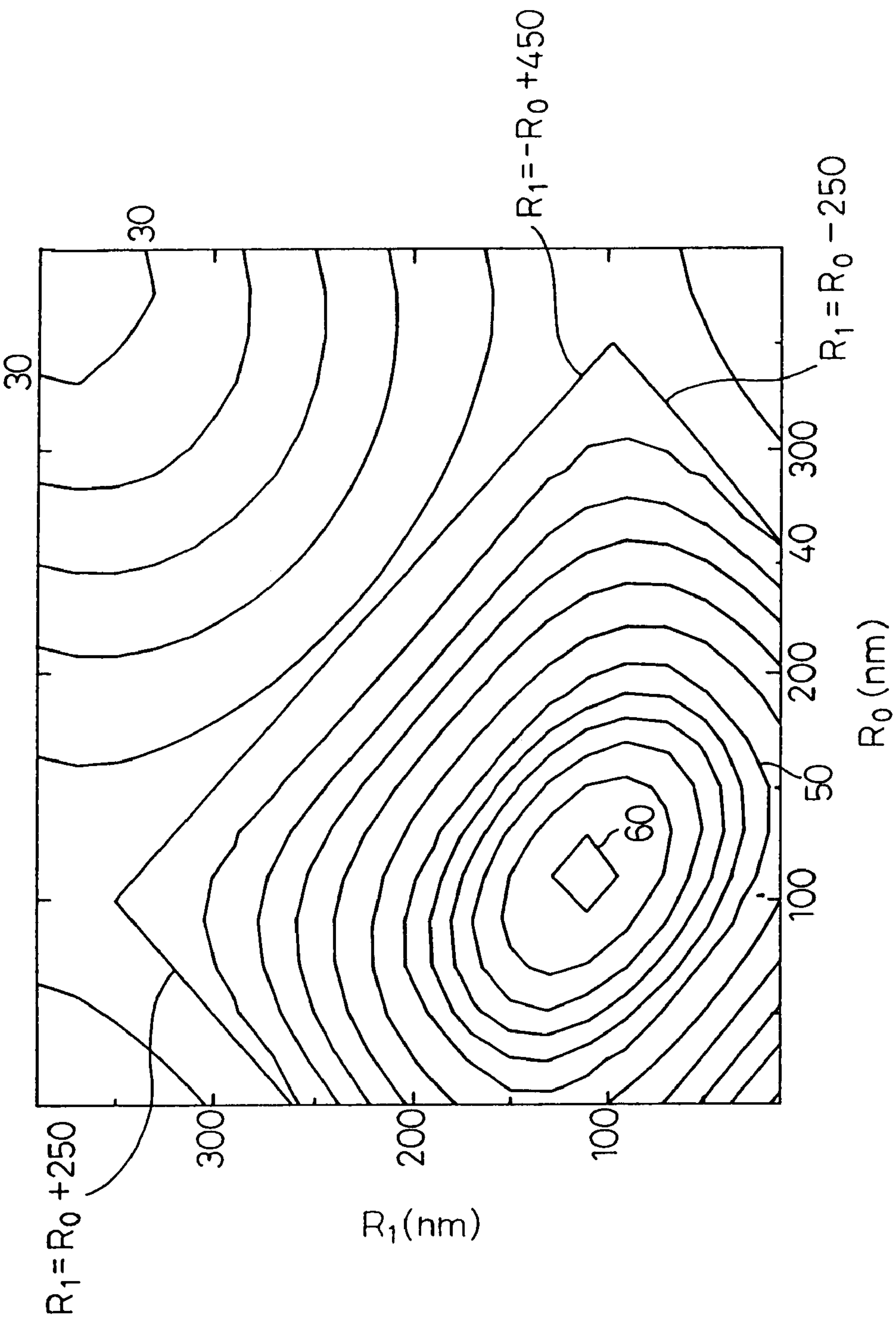


Fig. 221

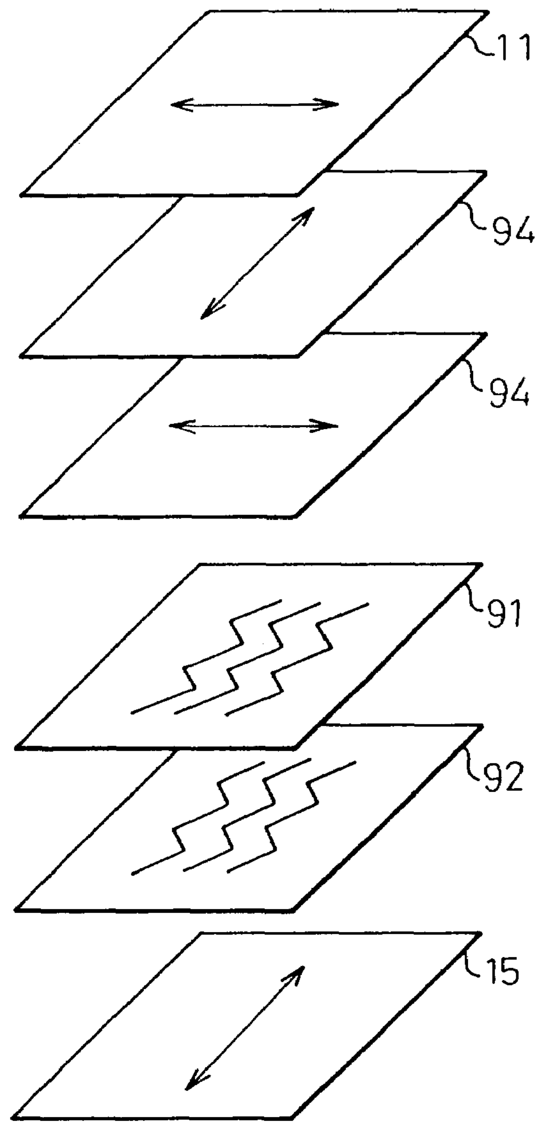


Fig. 222

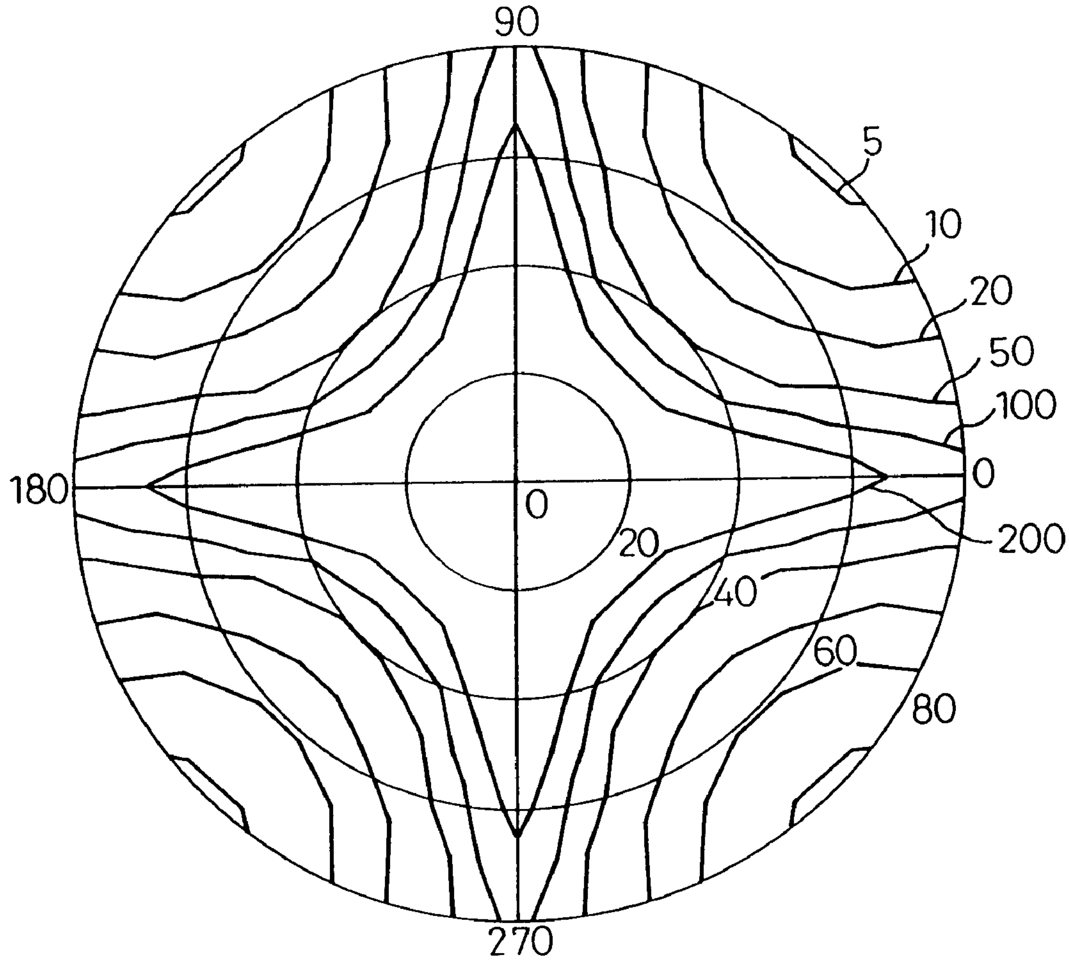


Fig. 223

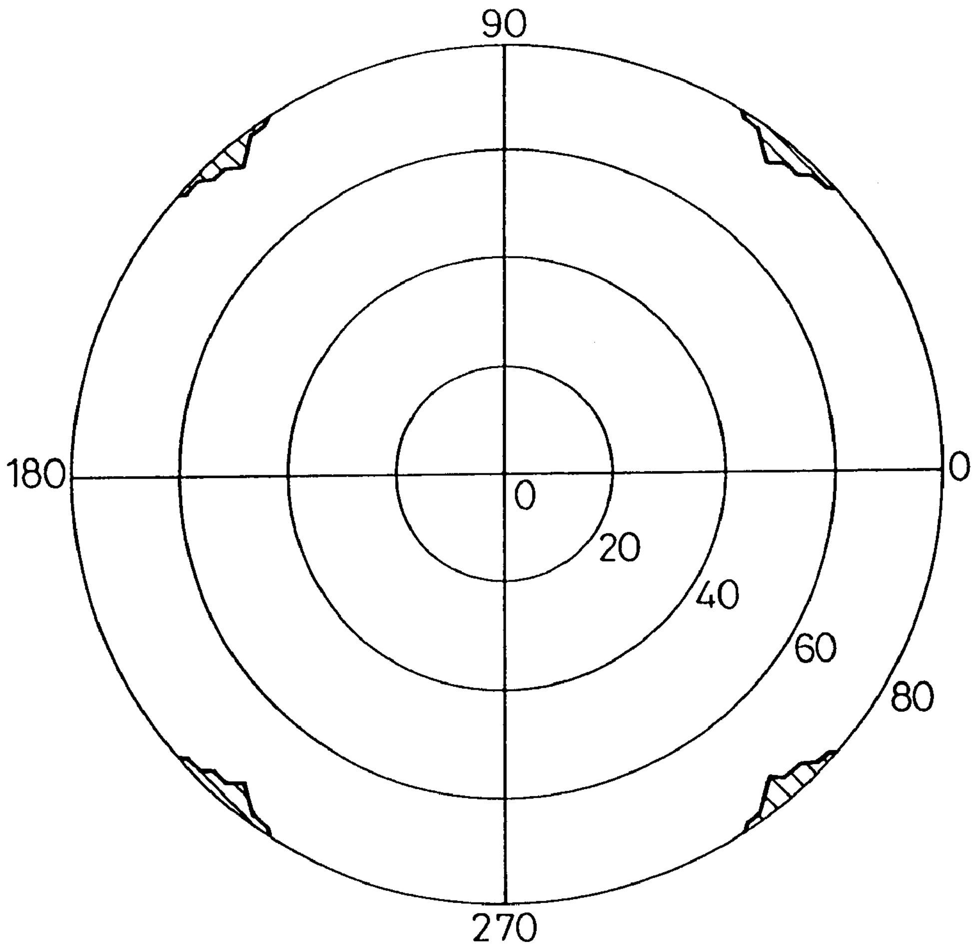
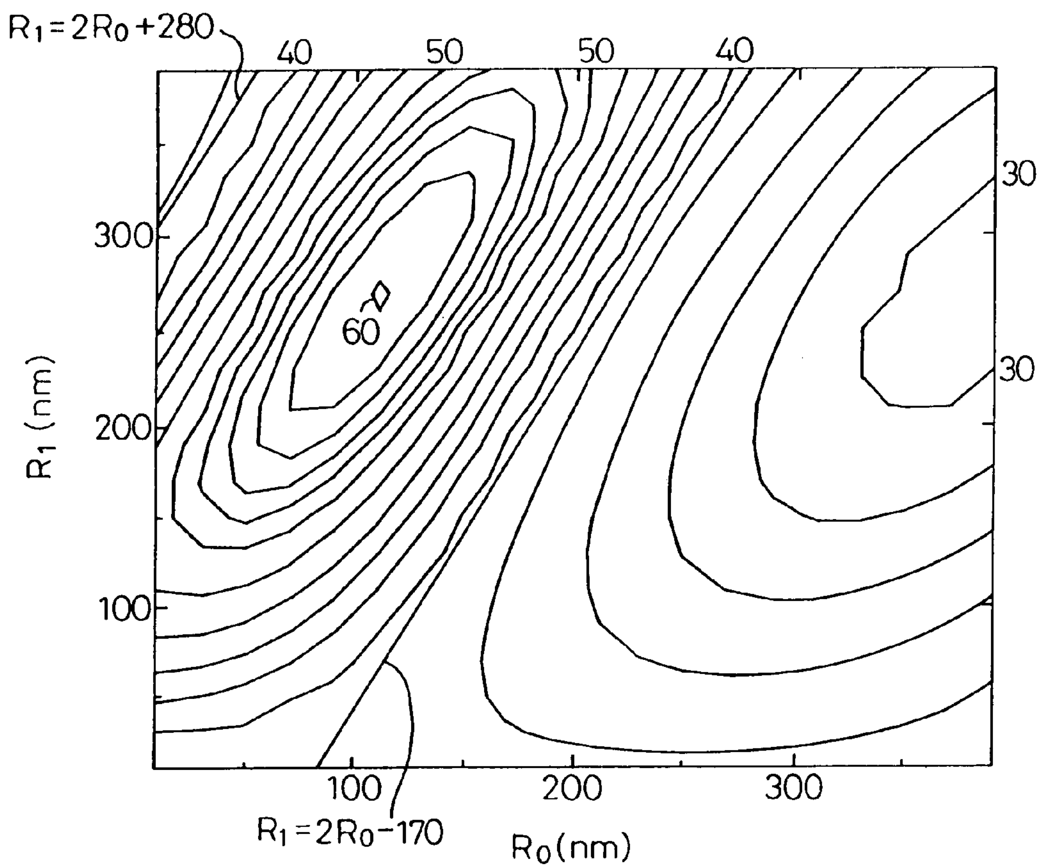


Fig.224



R1=2R0+280
40
50
50
40
30
30
60
300
200
100
R1 (nm)
100
200
300
R1=2R0-170
R0(nm)

Fig. 225

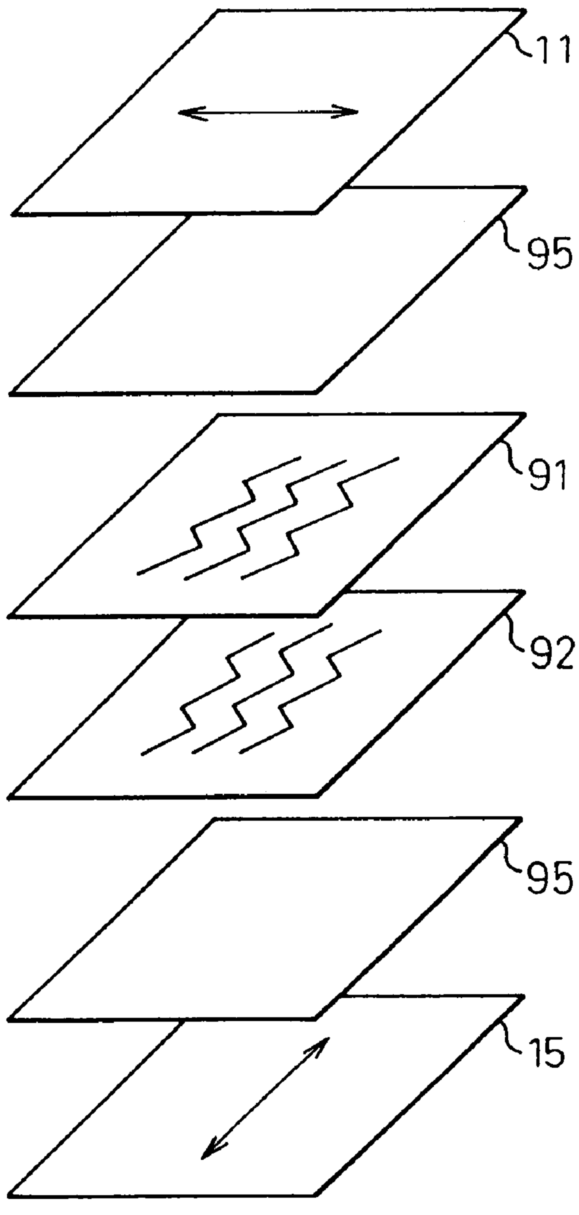


Fig. 226

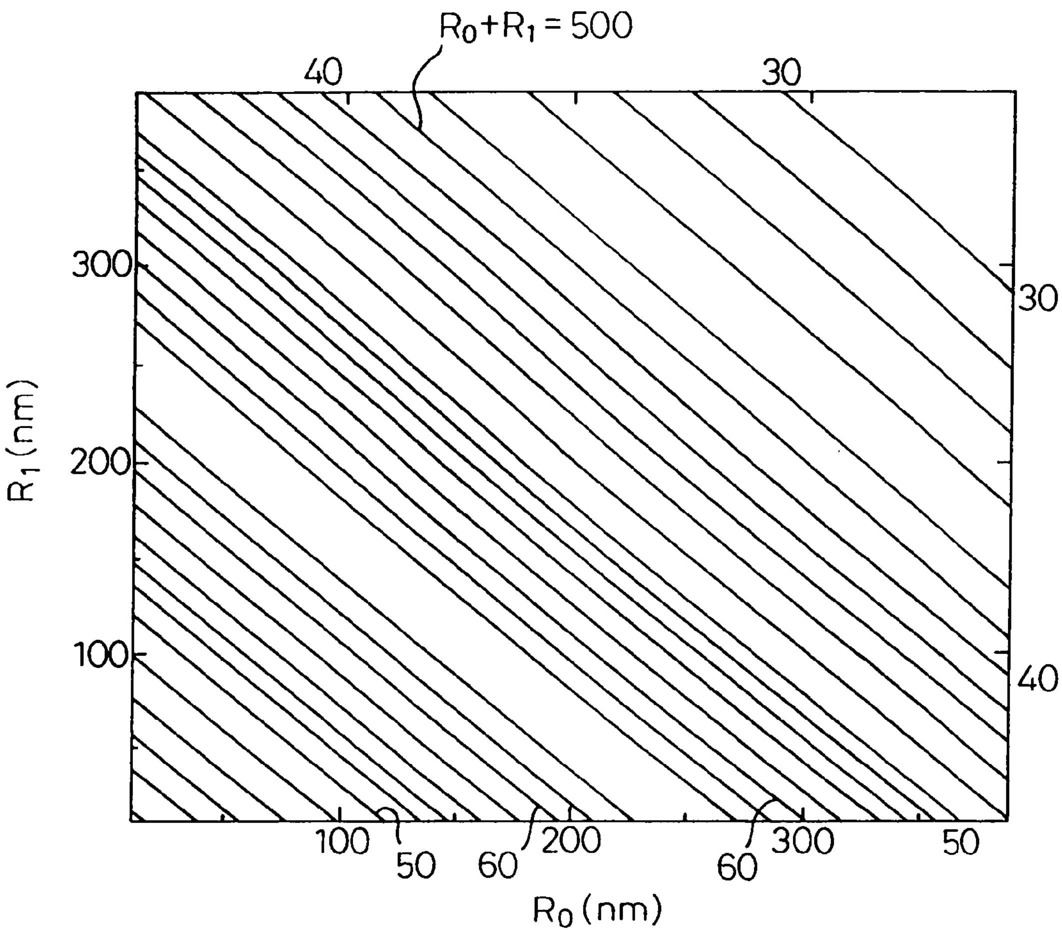
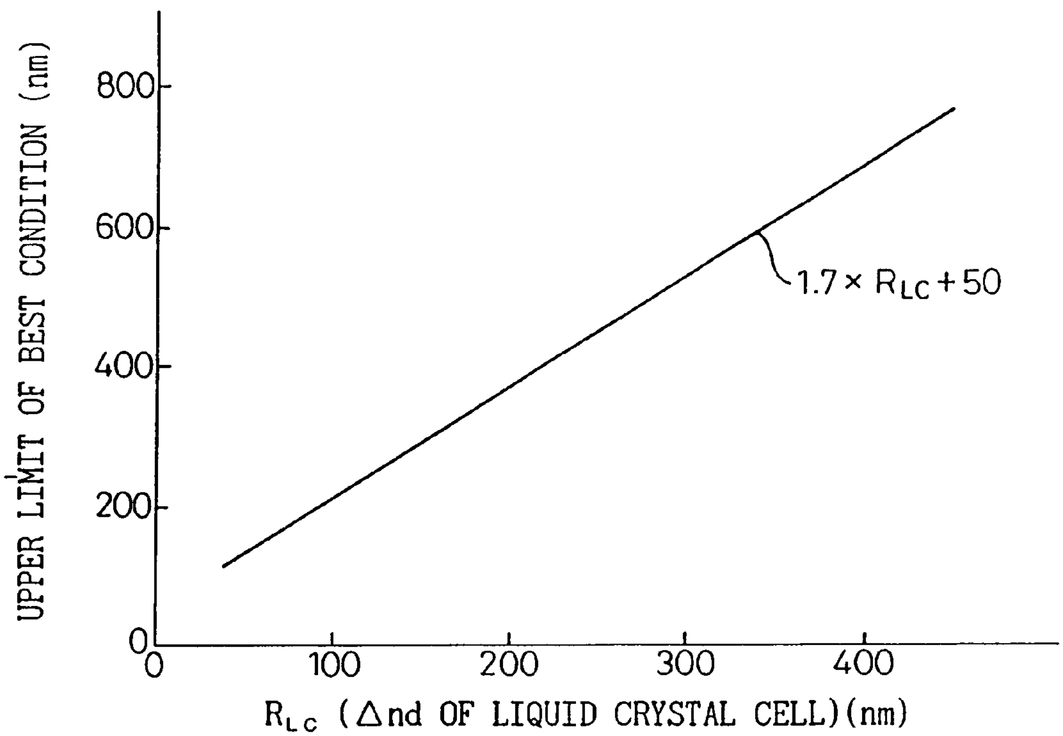


Fig.227



UPPER LIMIT OF BEST CONDITION (nm)
800
600
400
200
0
0
100
200
300
400
1.7× RLC+50
RLC (Δnd OF LIQUID CRYSTAL CELL)(nm)

Fig.228

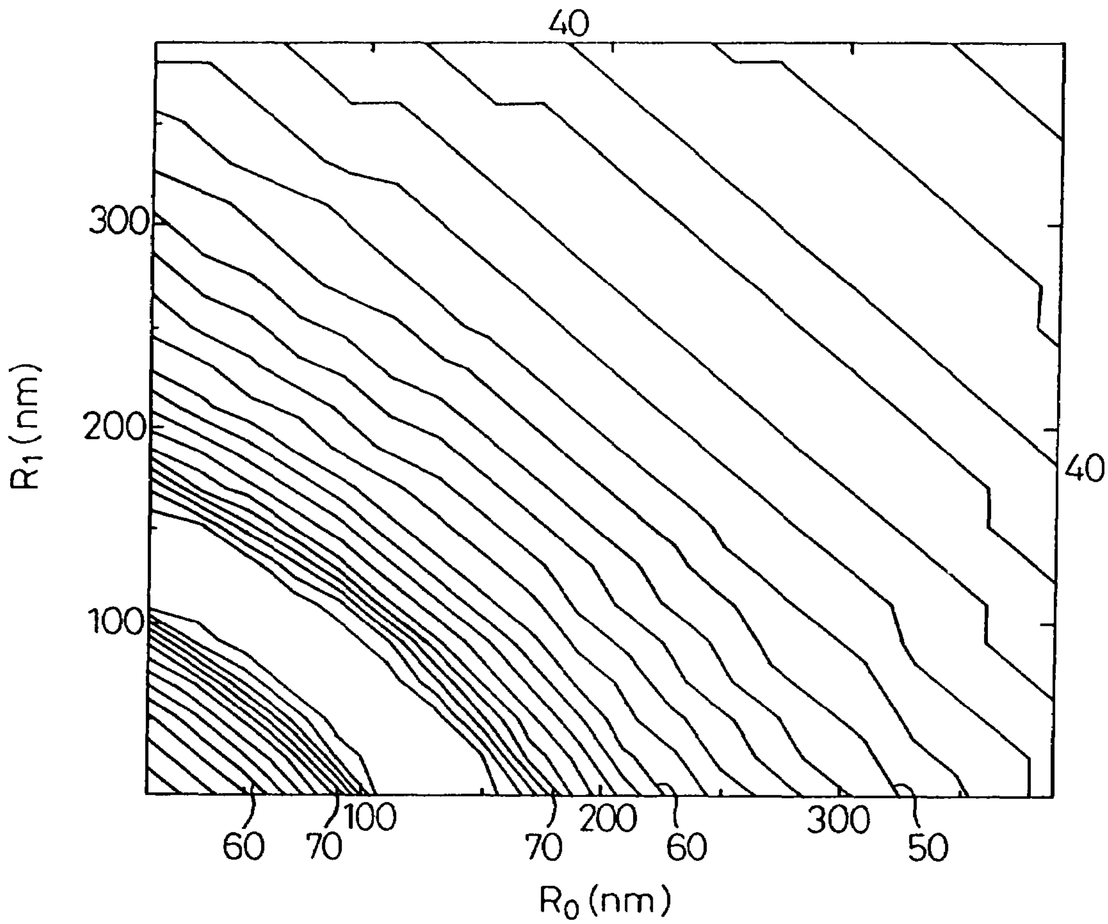


Fig. 229

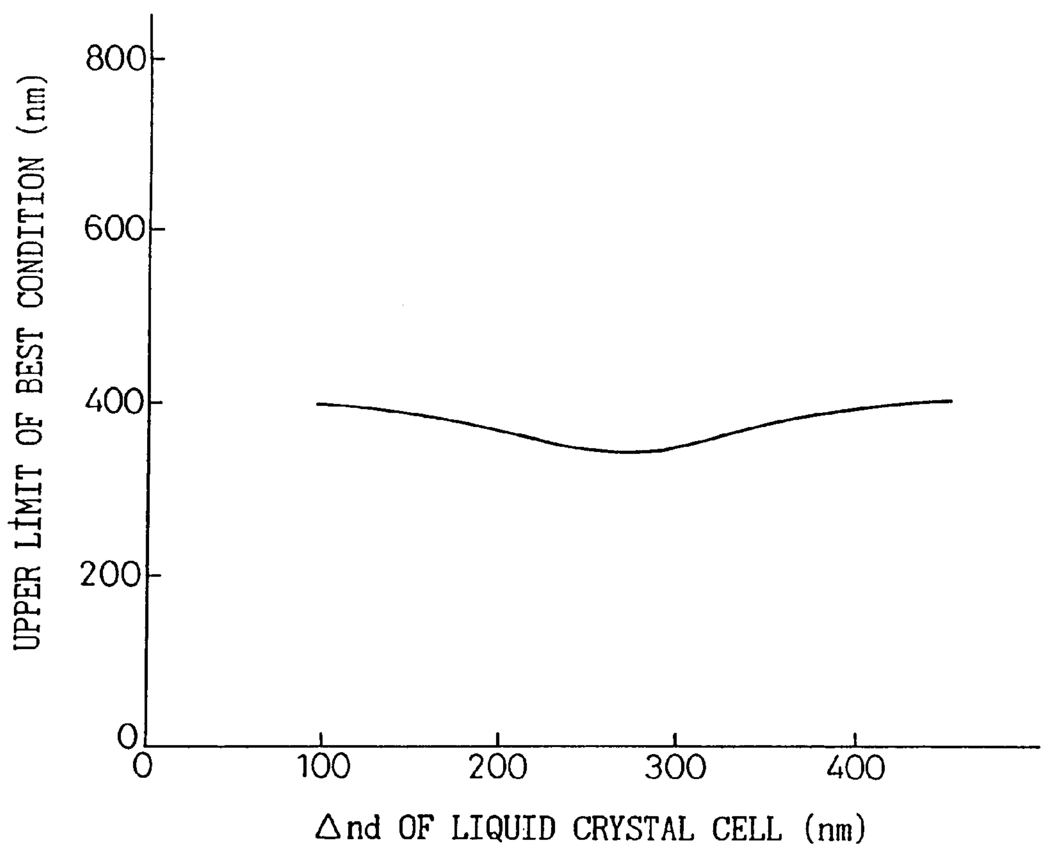

800
600
400
200
0
UPPER LIMIT OF BEST CONDITION (nm)
0
100
200
300
400
Δnd OF LIQUID CRYSTAL CELL (nm)

Fig.230

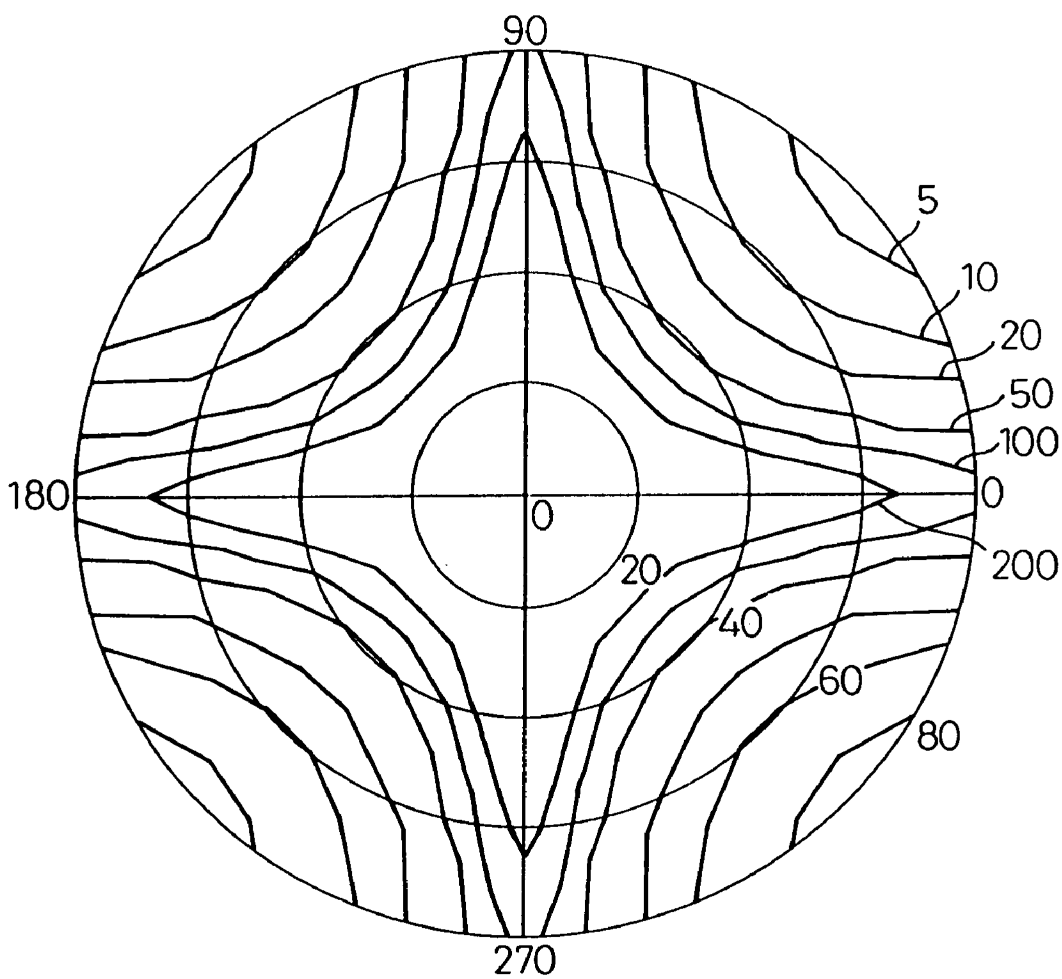


Fig. 231

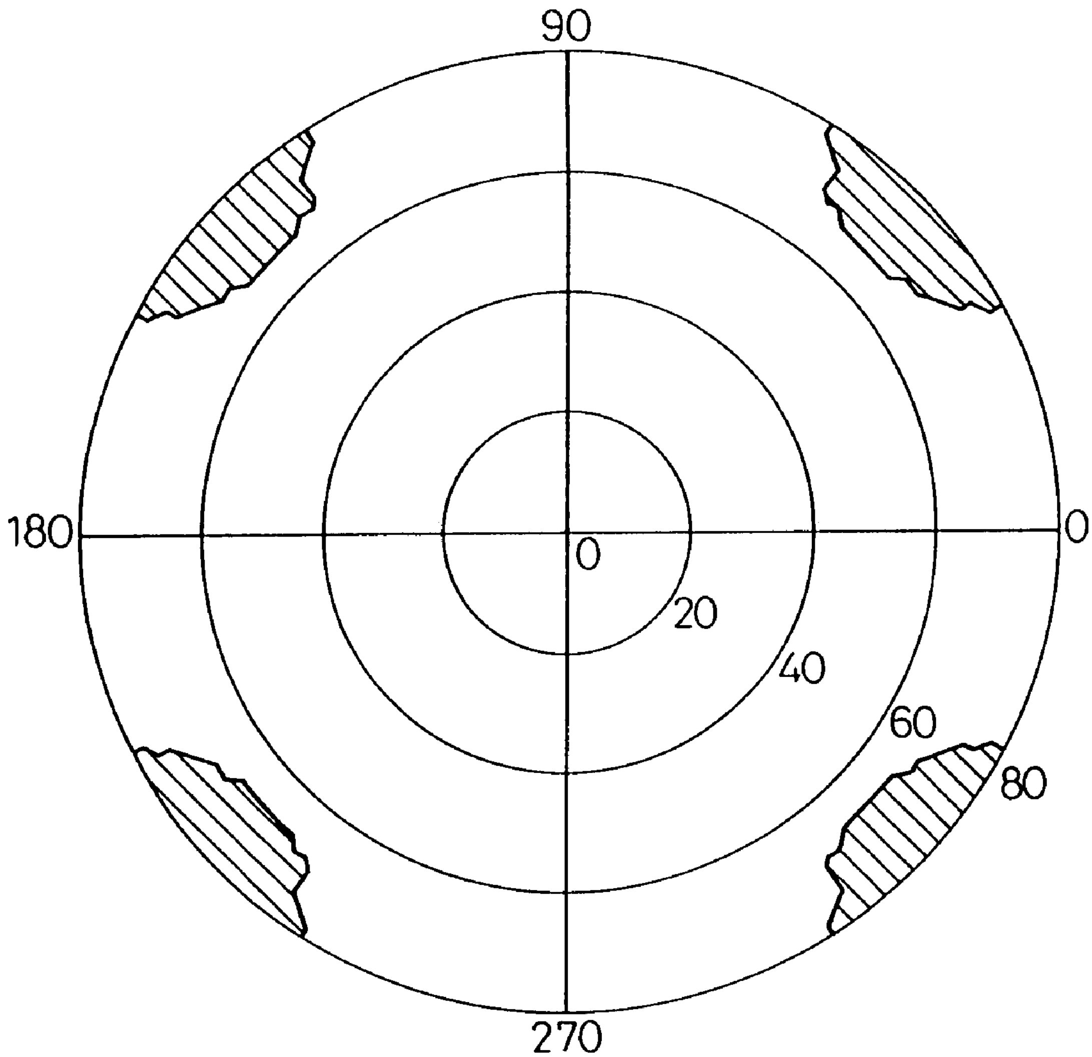


Fig. 232

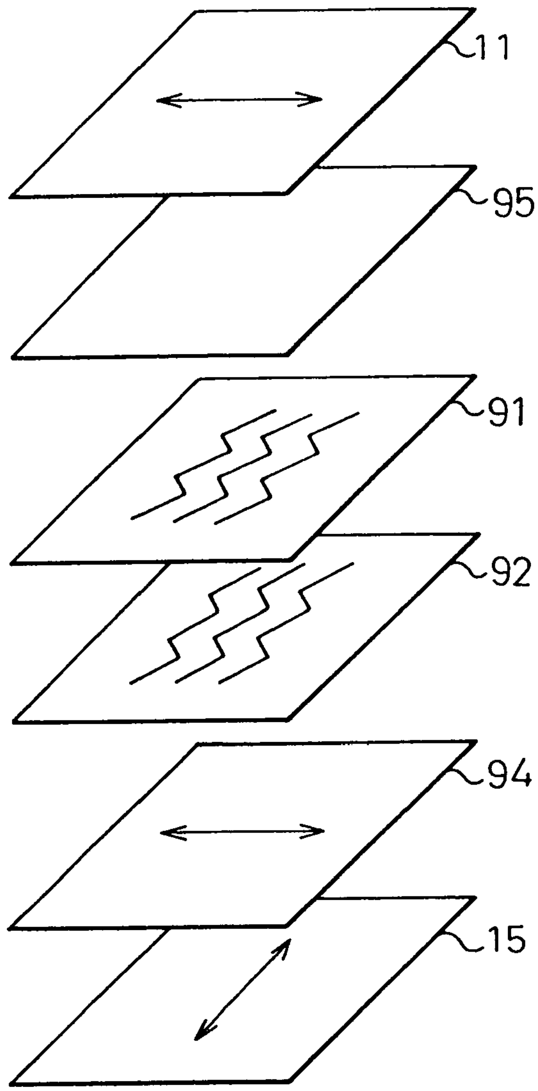


Fig. 233

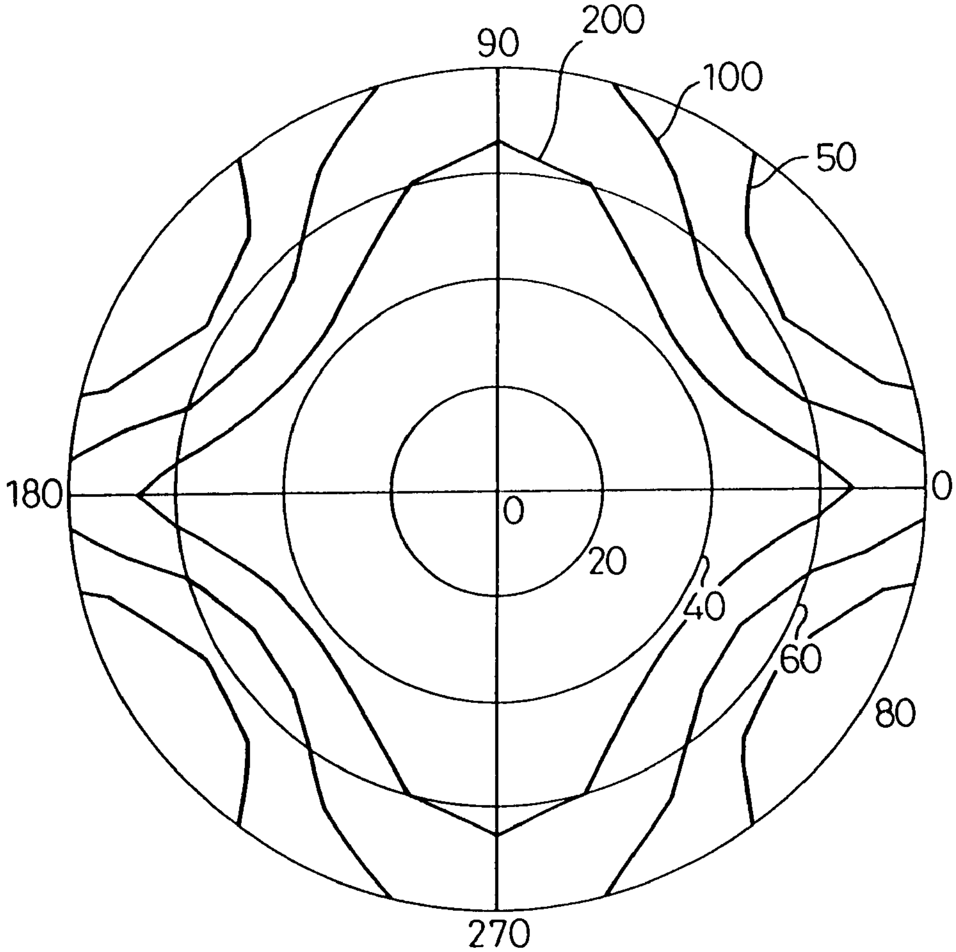


Fig. 234

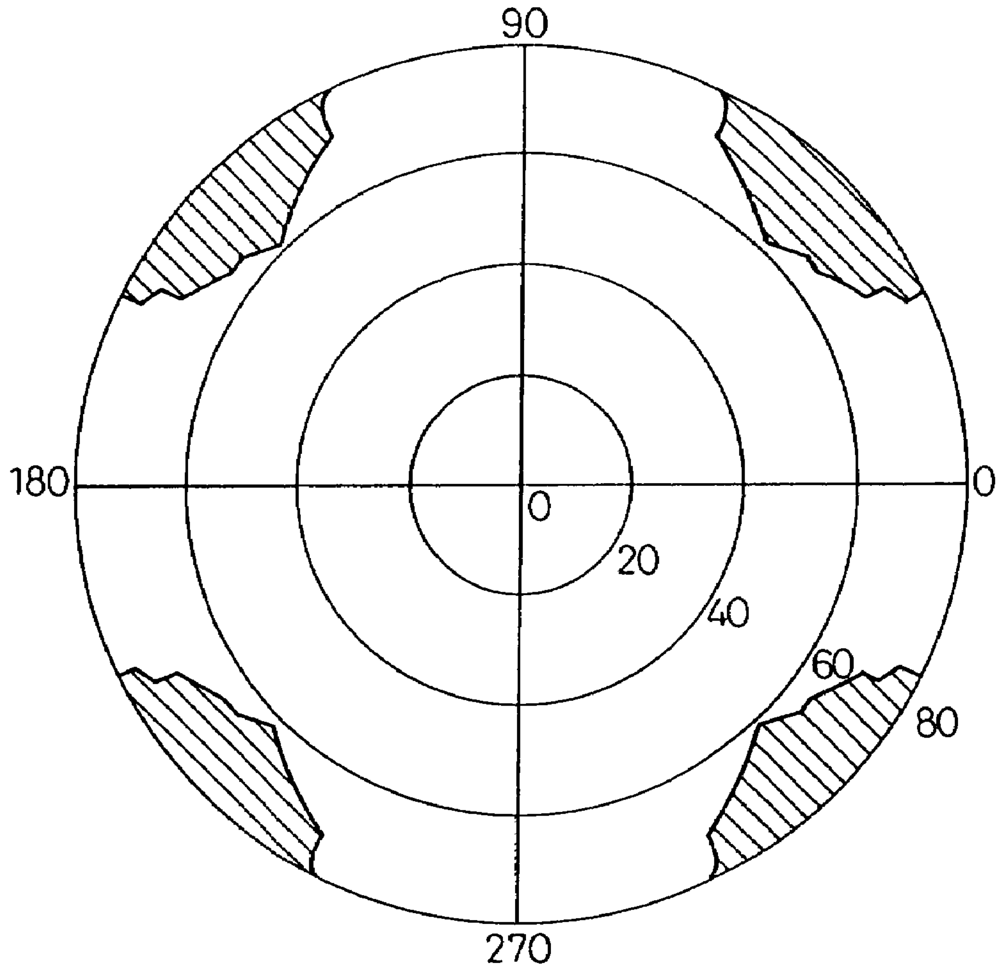


Fig. 235

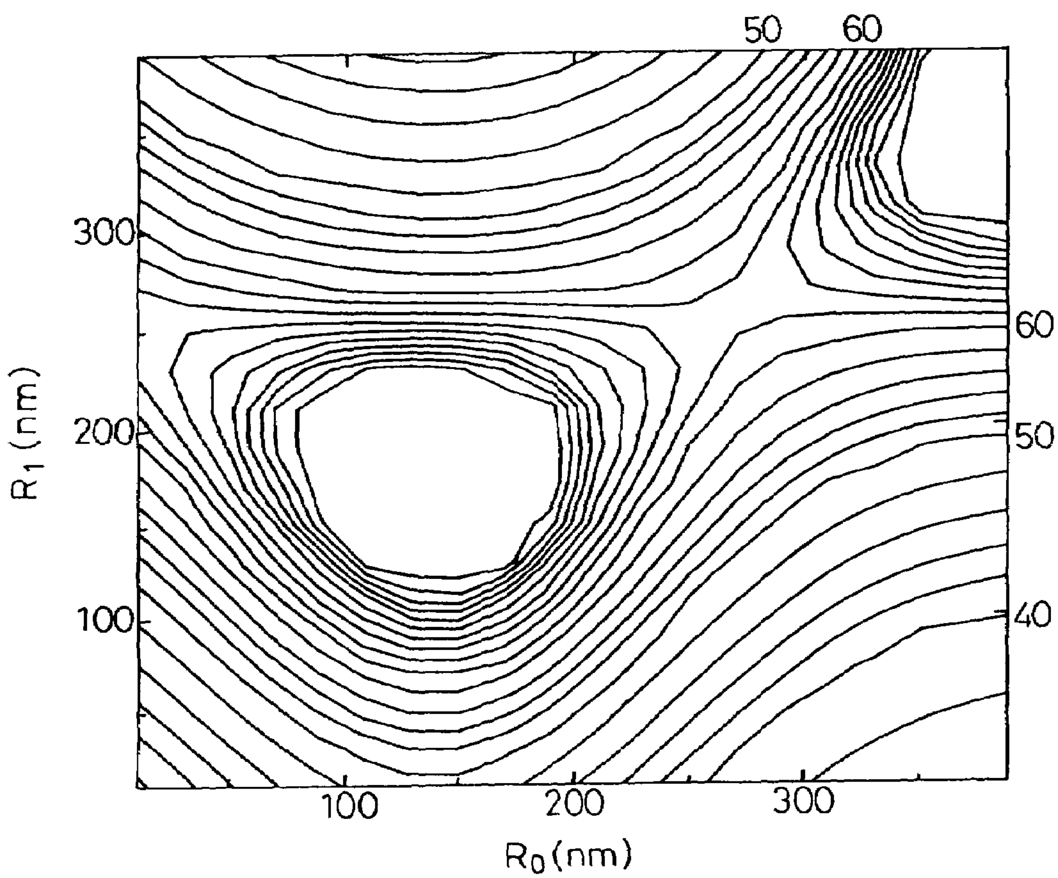


Fig.236

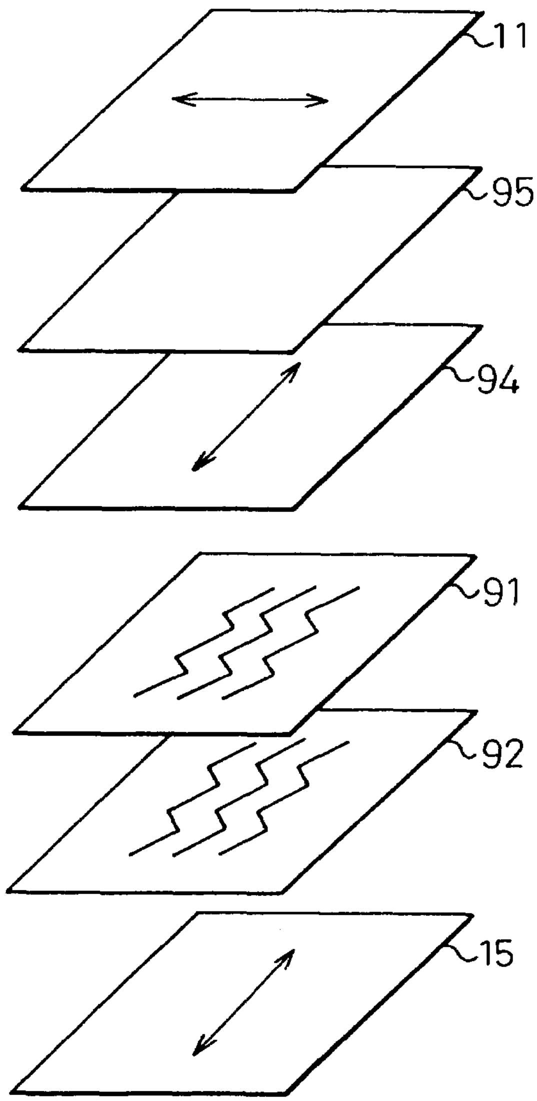


Fig.237

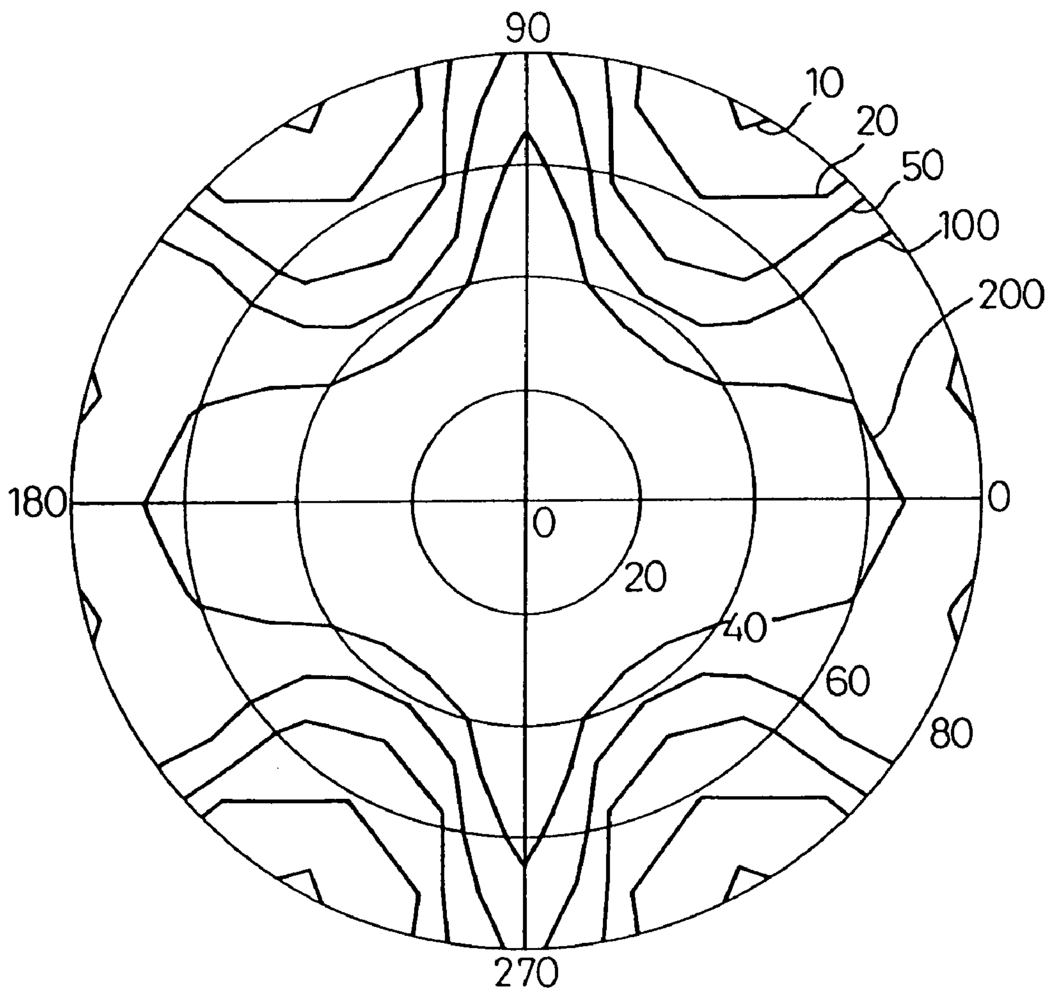


Fig. 238

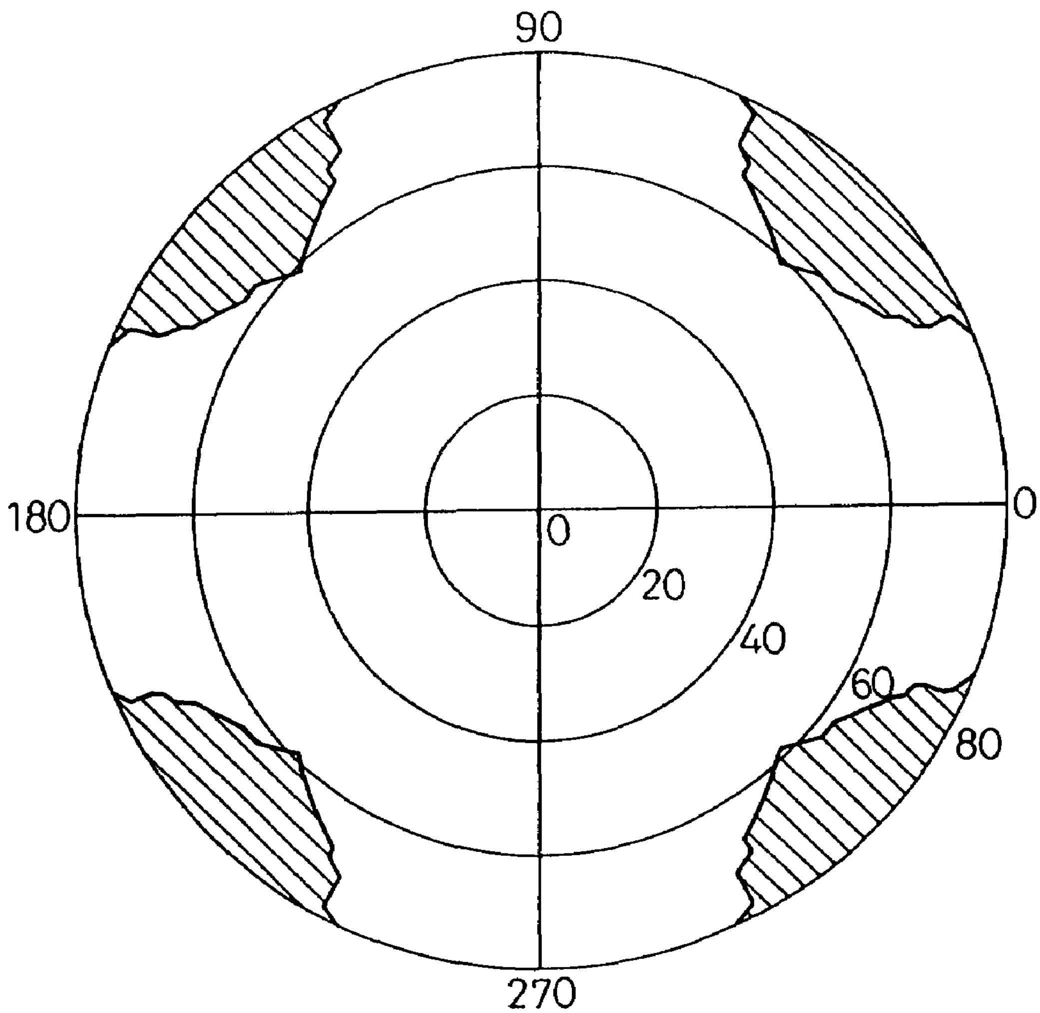


Fig.239

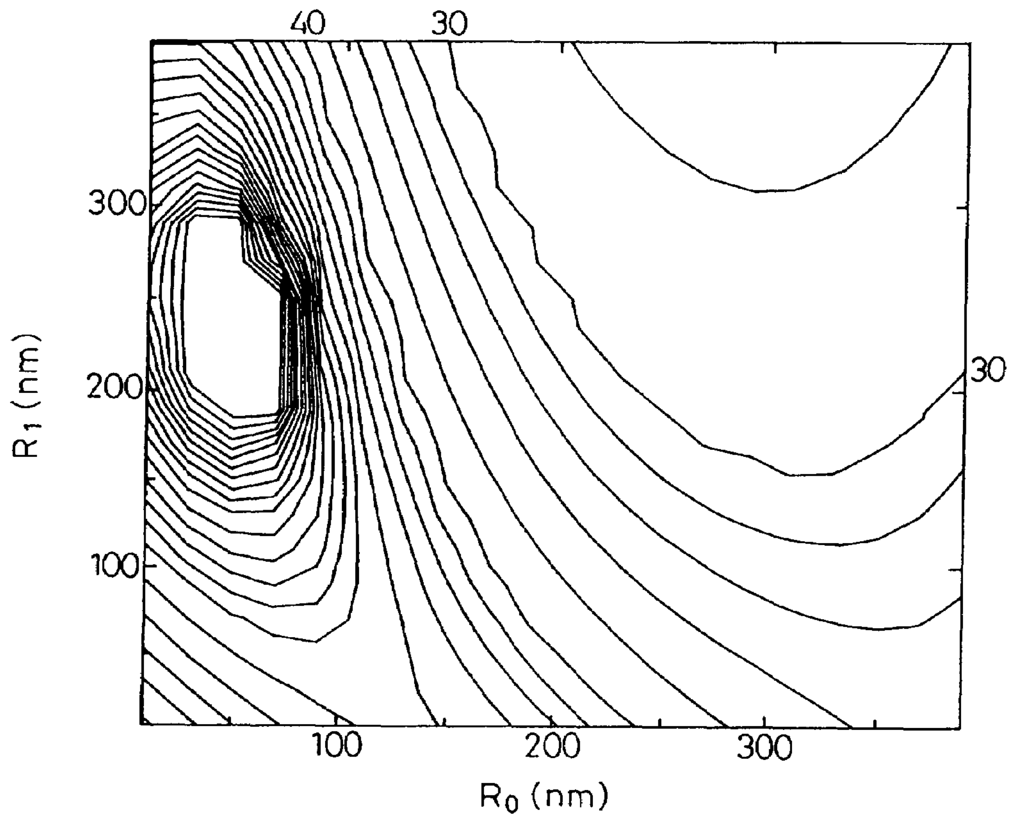


Fig. 240

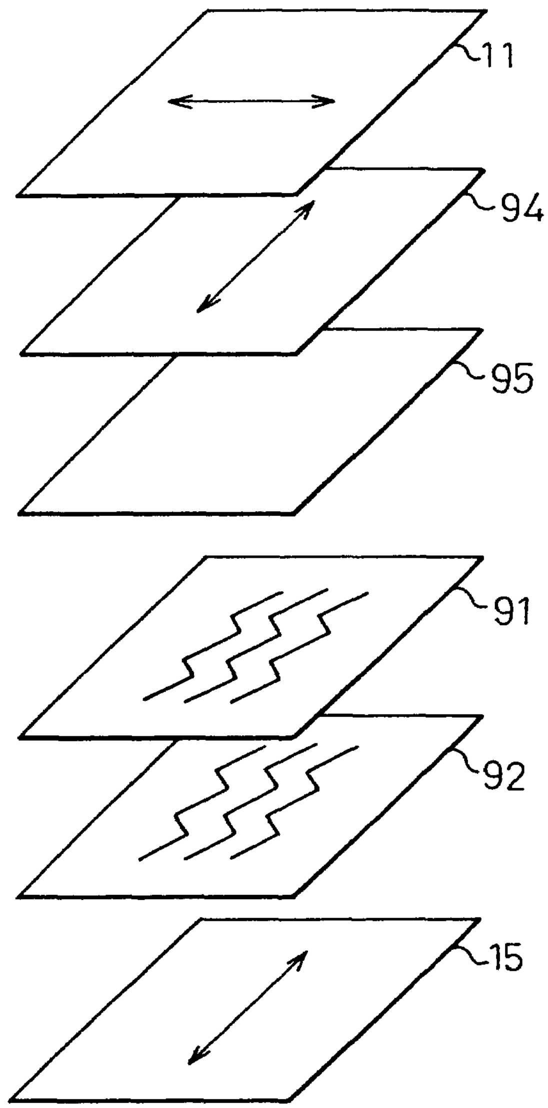


Fig.241

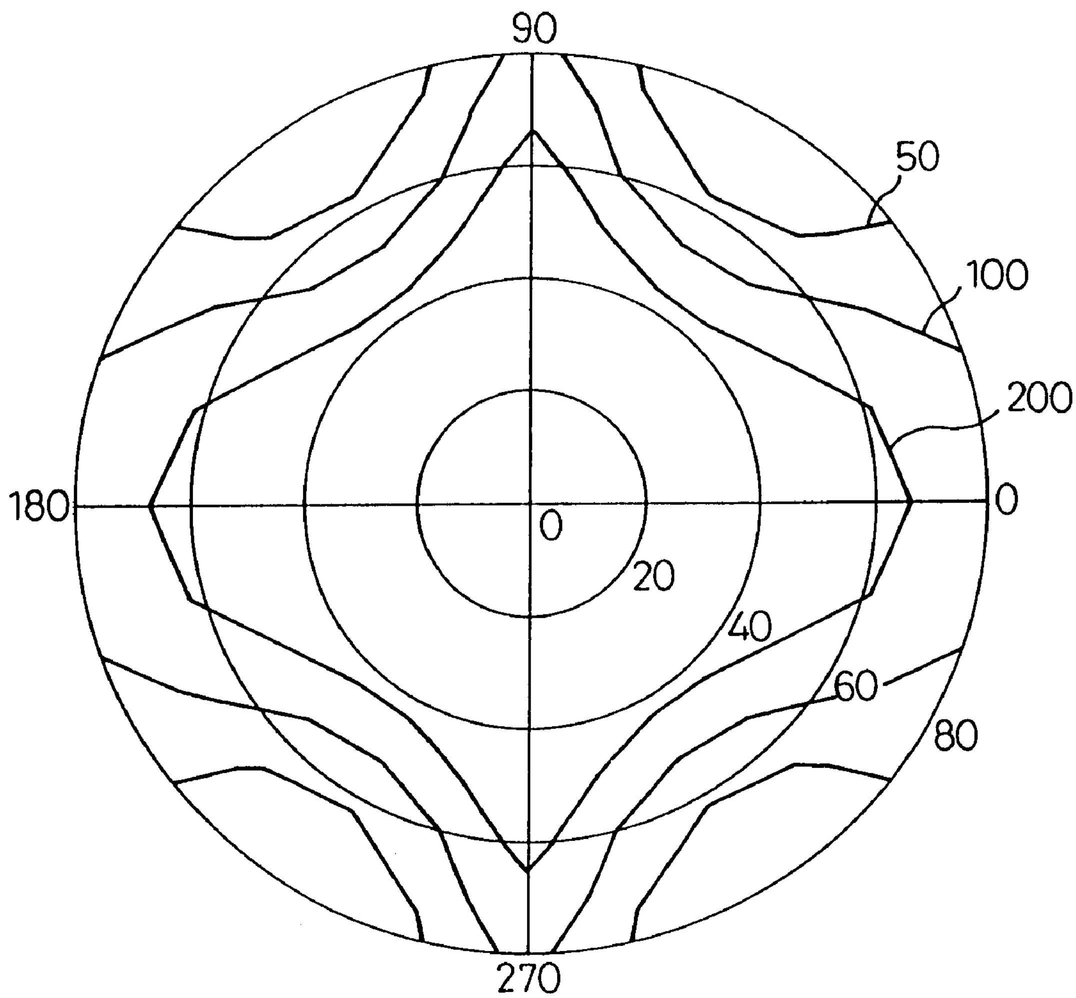


Fig. 242

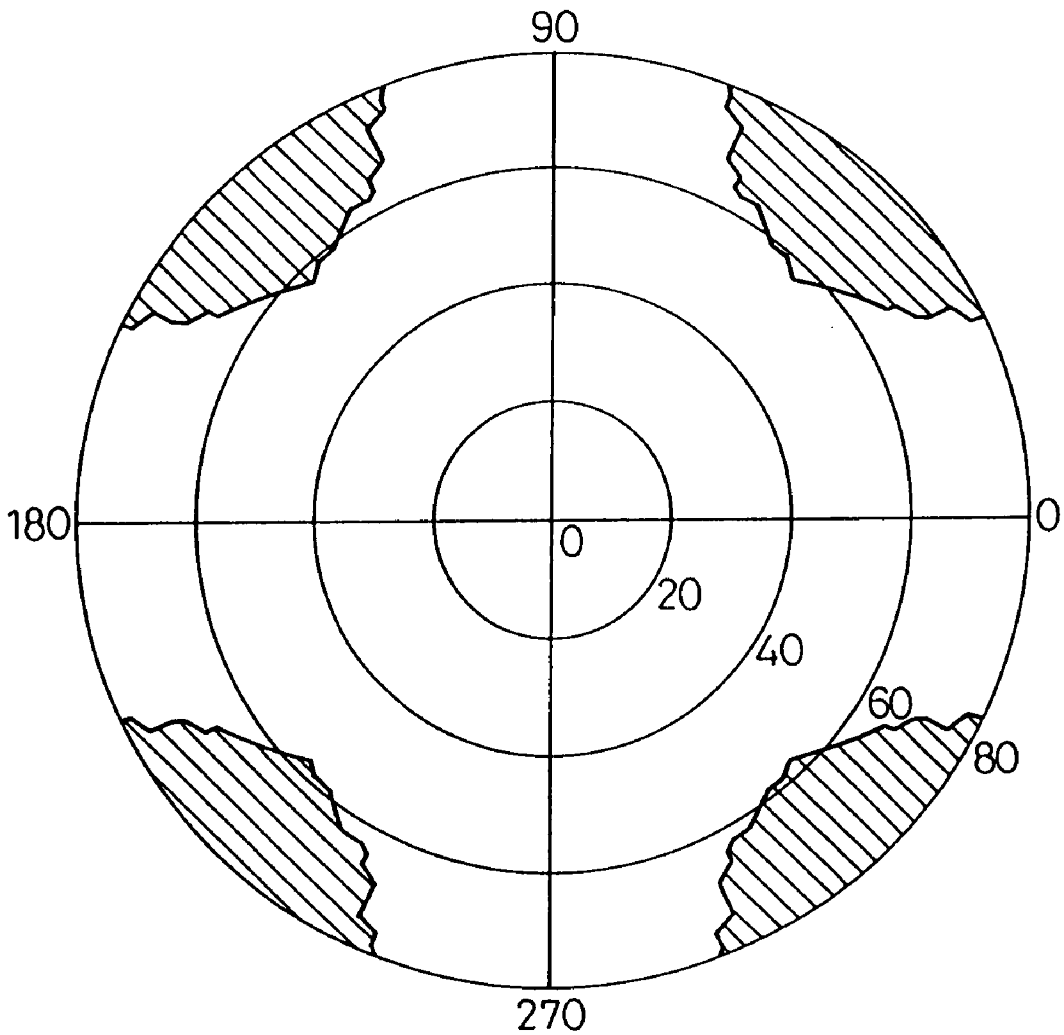


Fig.243

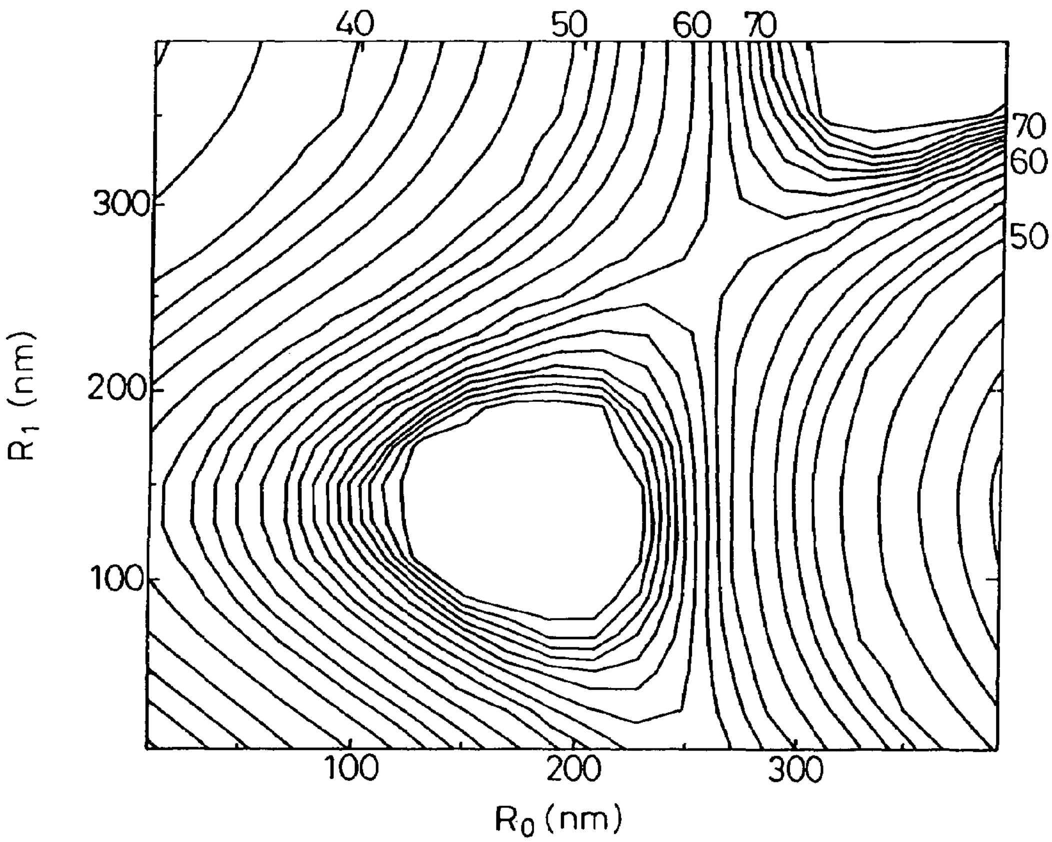


Fig. 244

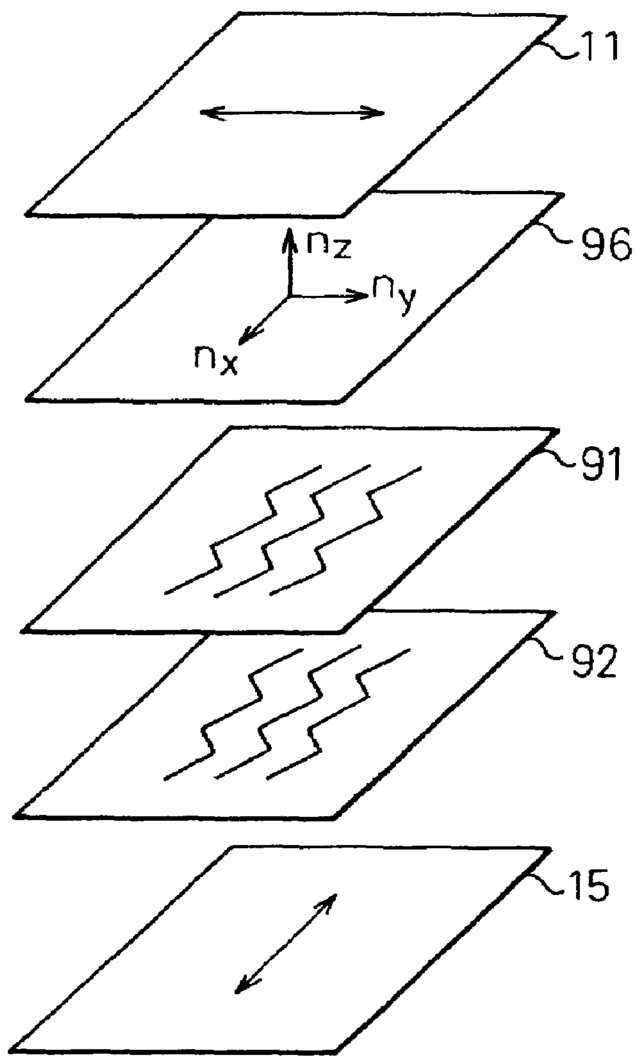


Fig.245

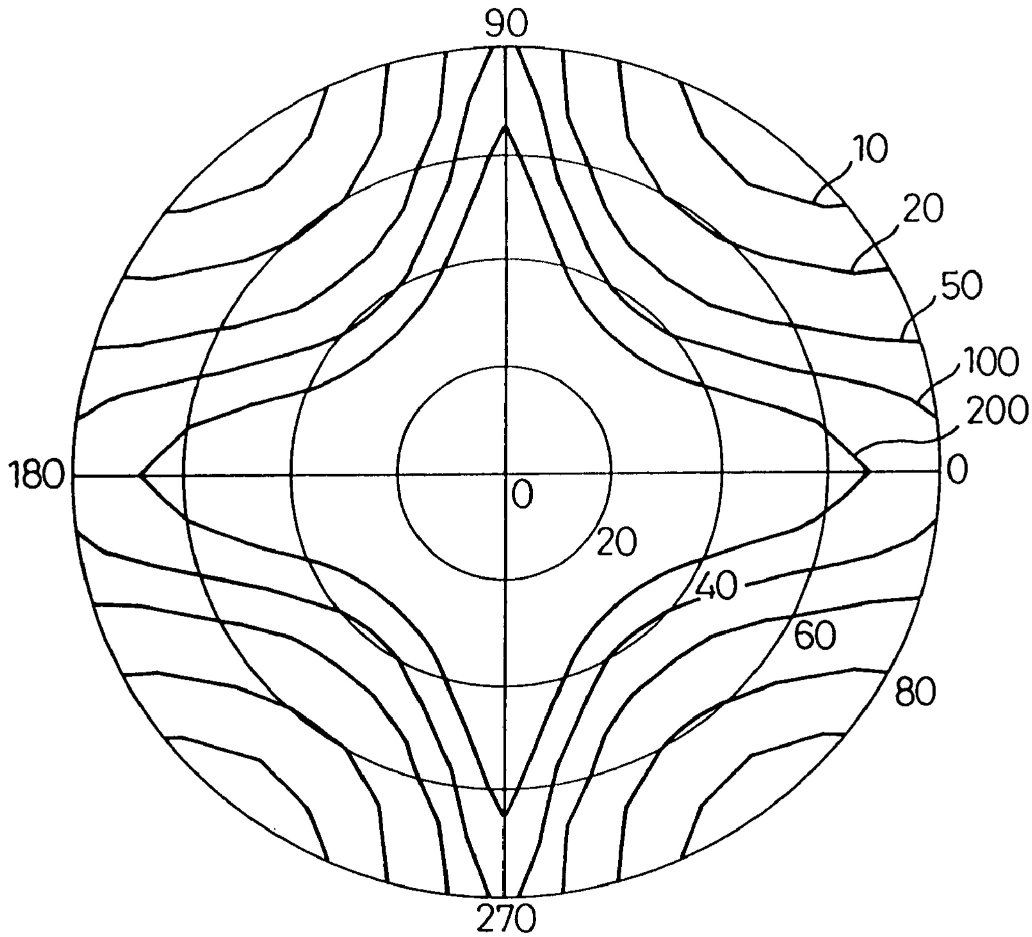


Fig. 246

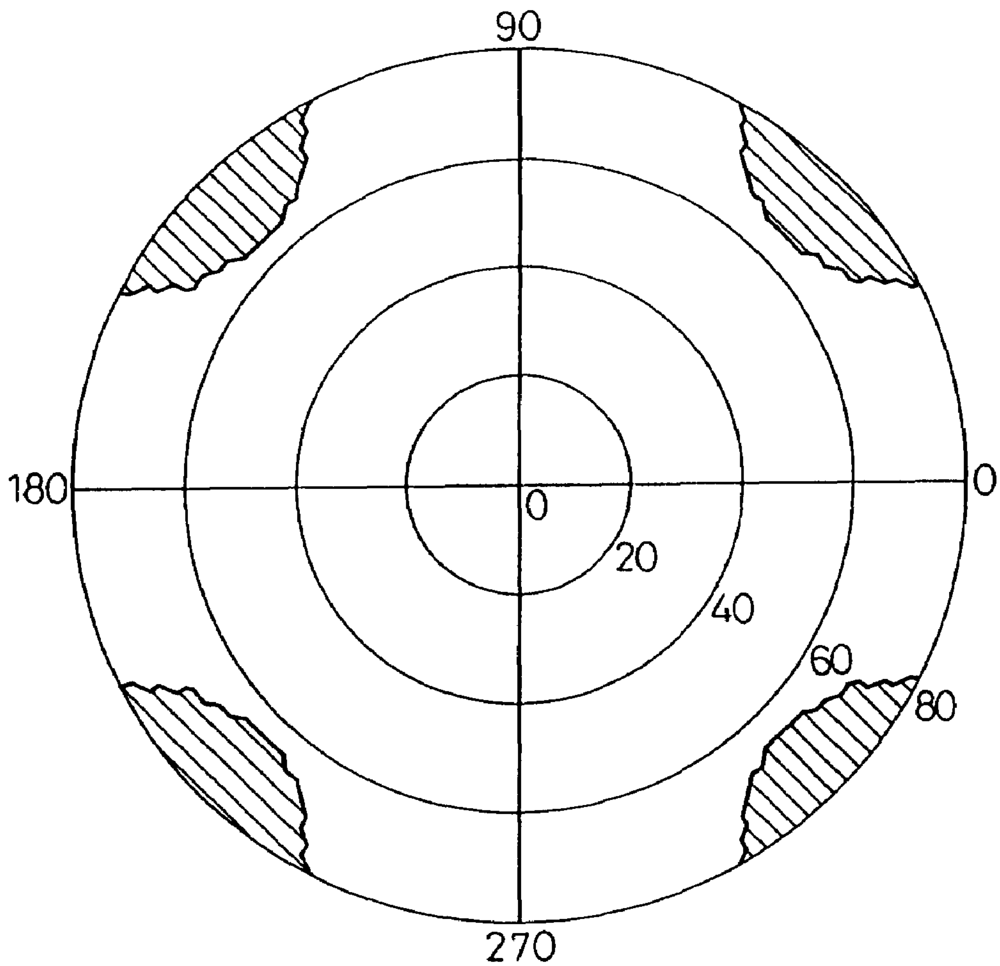
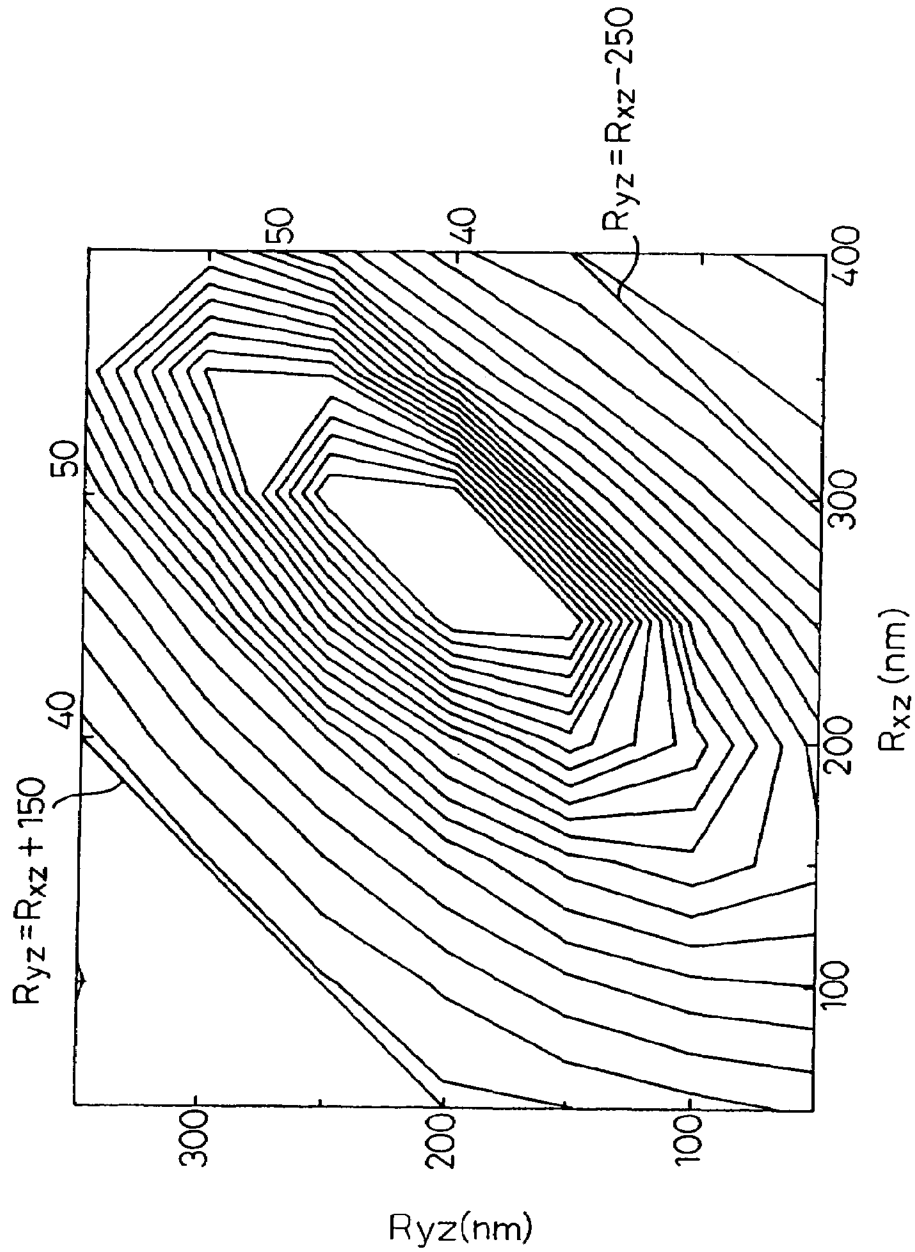


Fig. 247



Ryz=Rxz+150
Ryz=Rxz−250
40
50
50
40
300
200
100
Ryz(nm)
100
200
300
400
Rxz (nm)

Fig. 248

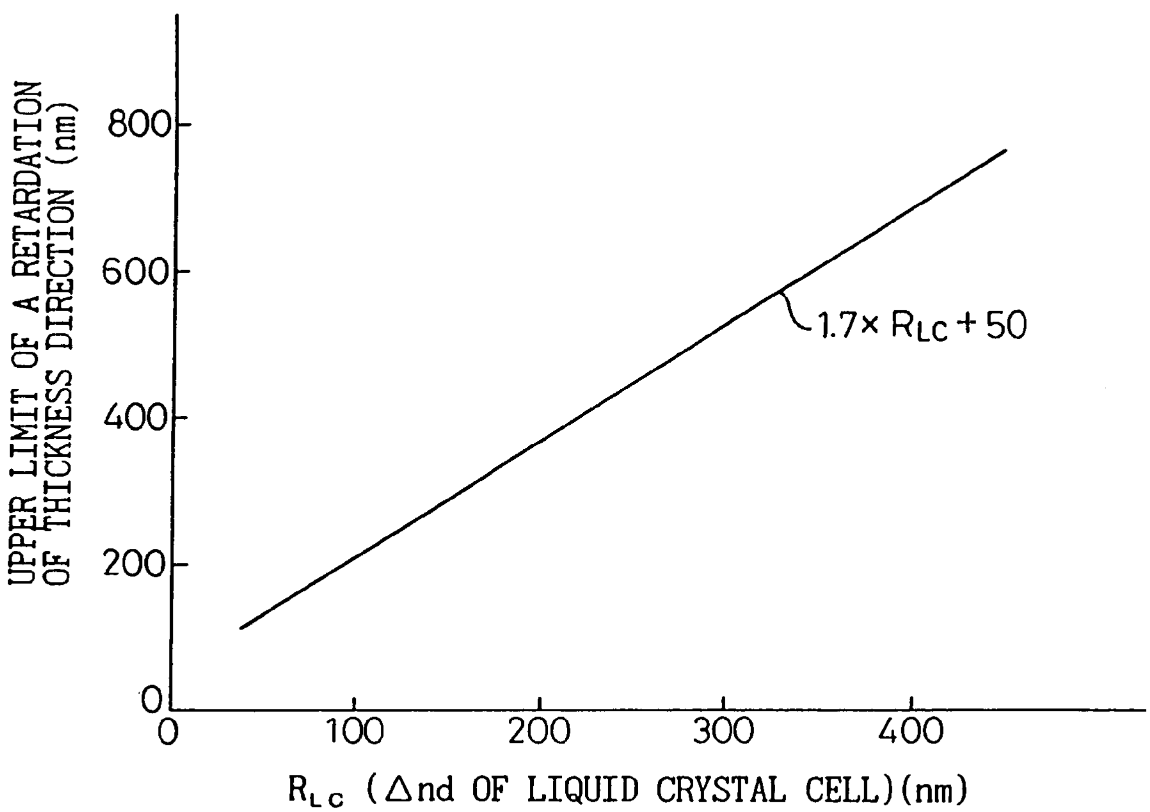

UPPER LIMIT OF A RETARDATION OF THICKNESS DIRECTION (nm)
800
600
400
200
0
1.7× RLC + 50
0
100
200
300
400
RLC (Δnd OF LIQUID CRYSTAL CELL)(nm)

Fig. 249

SAMPLE	THICKNESS OF A PANEL (μm) R G B	GAP BETWEEN PROJECTIONS (μm) R G B	PHASE DIFFERENCE FILM Rd VALUE (nm)	TRANS-MITTANCE % (5v)	VIEW ANGLE : CR >10 LEFT-RIGHT DIRECTION	COLOR DIFFERENCE (5v: LEFT -RIGHT) Δu(x)	Δv(Y)
EMBODIMENT A	5.7, 4.6, 3.6	20, 25, 30	320	5.60	± 80°	0.03	0.03
EMBODIMENT B	5.7, 4.6, 3.6	20, 25, 30	320	5.60	± 80°	0.03	0.05
PRIOR ART 1	R,G,B=3.6	R,G,B=30	240	4.50	± 80°	0.06	0.05
PRIOR ART 2	R,G,B=4.6	R,G,B=30	320	5.80	± 80°	0.14	0.12

Fig. 250

EXAMPLES	INITIAL VALUES	AFTER 200 HOURS
EMBODIMENT C	25	42
EMBODIMENT D	33	51
EMBODIMENT E	26	45
EMBODIMENT F	30	48
REFERENCE	32	70

Fig.251A

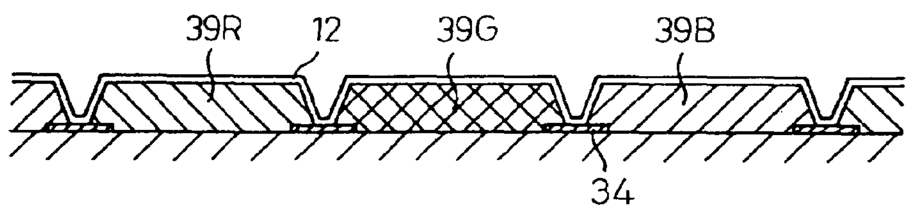


Fig.251B

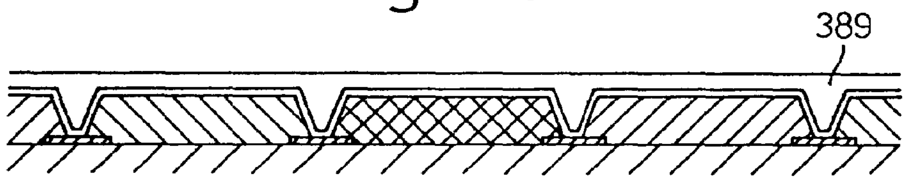


Fig.251C

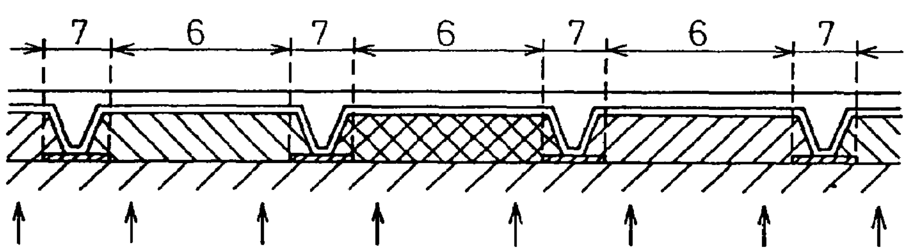


Fig.251D

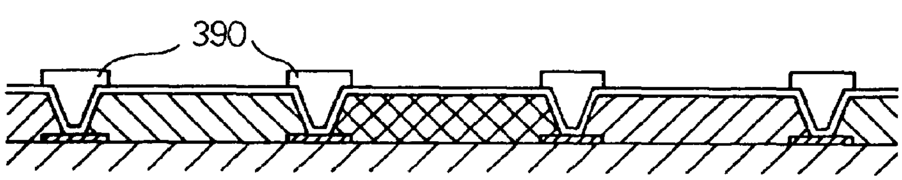


Fig.252A

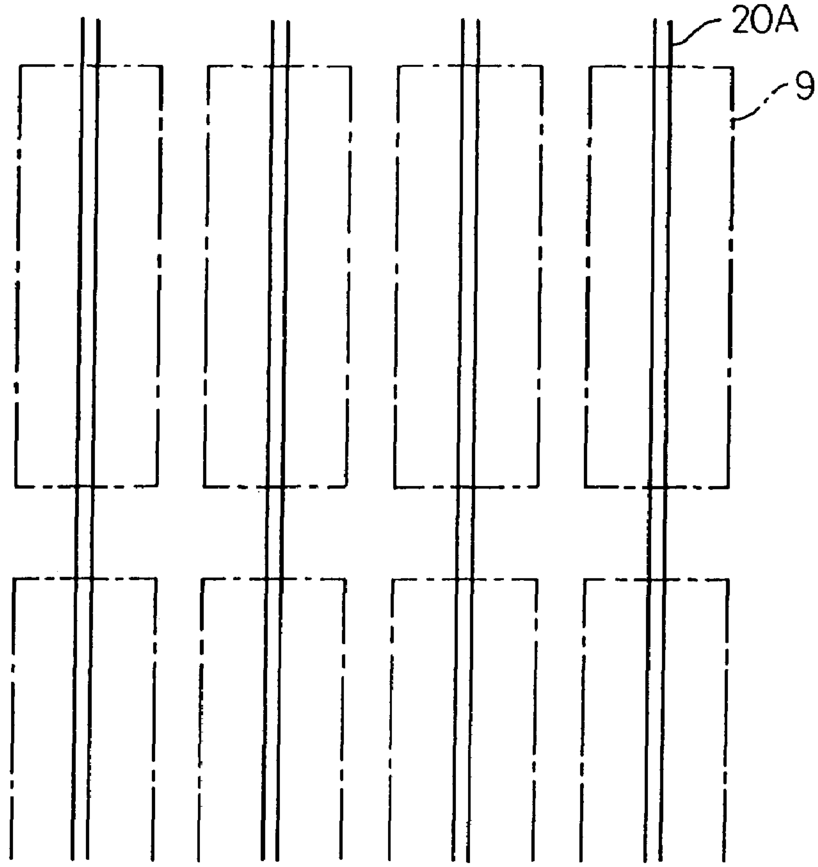


Fig.252B

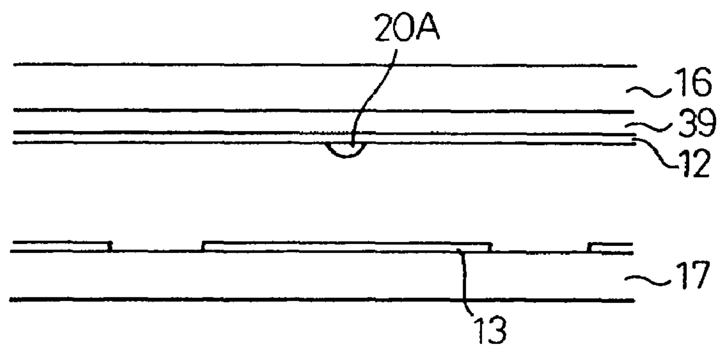


Fig. 253

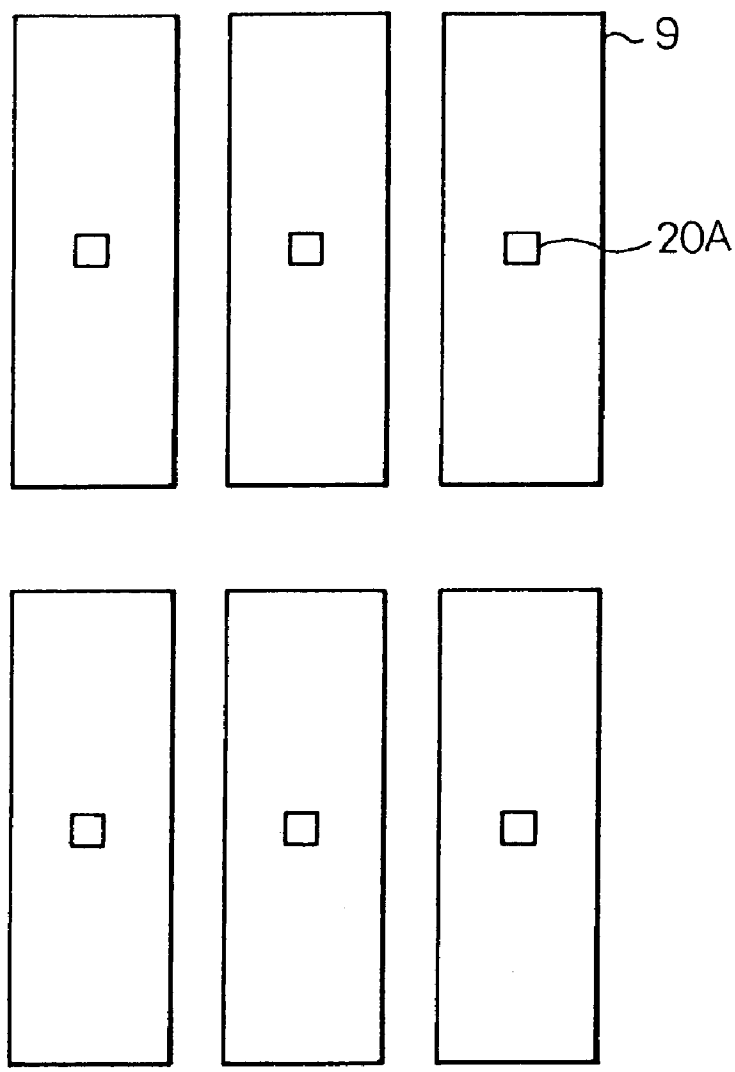


Fig.254A

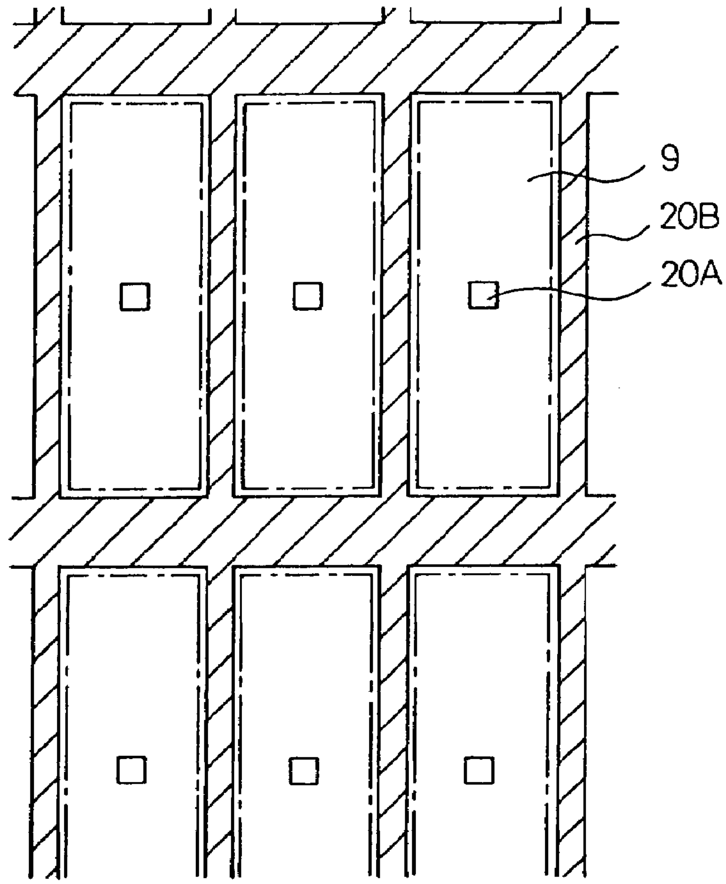


Fig.254B

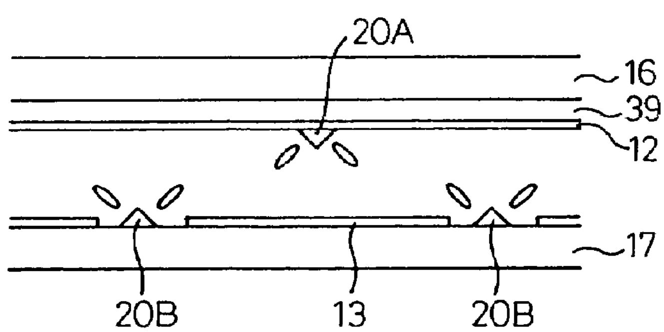
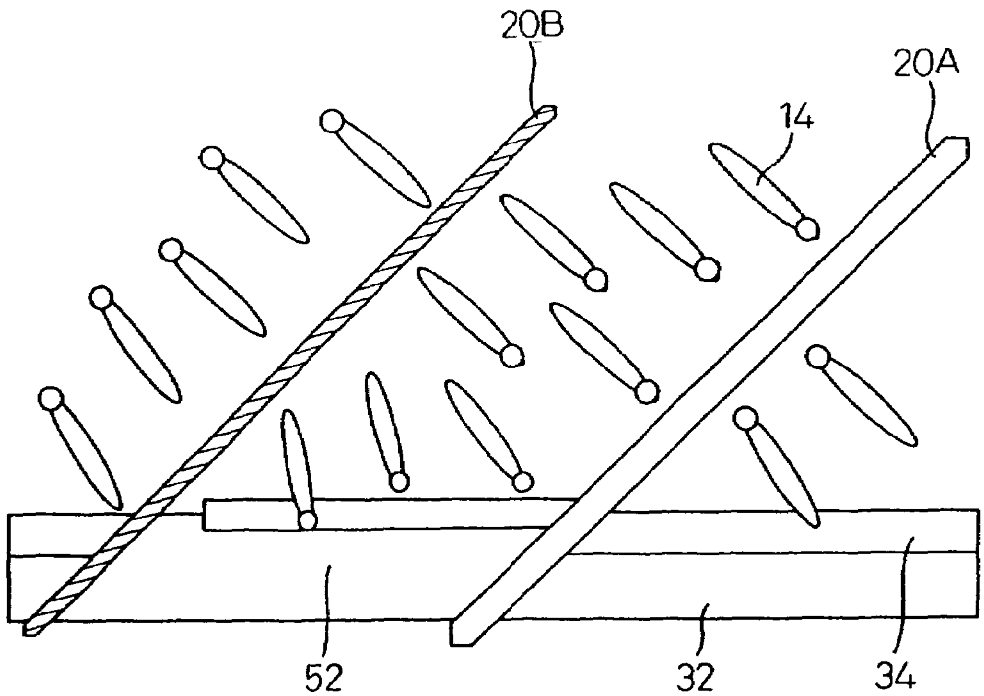


Fig.255



VERTICALLY-ALIGNED (VA) LIQUID CRYSTAL DISPLAY DEVICE

This is a divisional of application Ser. No. 09/097,027, filed Jun. 12, 1998 now U.S. Pat. No. 6,724,452.

BACKGROUND OF THE INVENTION

The present invention relates to a liquid crystal display (LCD), or more particularly, to a technology for realizing orientation division for a vertically-aligned (VA) LCD.

Among flat-panel displays enjoying image quality equivalent of the one offered by the CRT, it is a liquid crystal display (LCD) that has been most widely adopted nowadays. In particular, a thin-film transistor (TFT) type LCD (TFT LCD) has been adapted to public welfare-related equipment such as a personal computer, word processor, and OA equipment, and home electric appliances including a portable television set, and expected to further expand its market. Accordingly, there is a demand for further improvement of image quality. A description will be made by taking the TFT LCD for instance. However, the present invention is not limited to the TFT LCD but can apply to a simple matrix LCD, a plasma addressing type LCD and so forth. Generally, the present invention is applicable to LCDs which include liquid crystal sandwiched between a pair of substrates on which electrodes are respectively formed and carry out displays by applying voltage between the electrodes.

Currently, a mode most widely adopted for the TFT LCD is a normally-white mode that is implemented in a twisted nematic (TN) LCD. The technology of manufacturing the TN TFT LCD has outstandingly advanced in recent years. Contrast and color reproducibility provided by the TN TFT LCD have surpassed those offered by the CRT. However, the TN LCD has a critical drawback of a narrow viewing angle range. This poses a problem that the application of the TN LCD is limited.

In an effort to solve these problems, Japanese Examined Patent Publication Nos. 53-48452 and 1-120528 have proposed an LCD adopting a mode referred to as an IPS mode.

However, the IPS mode suffers from slow switching. At present, when a motion picture representing a fast motion is displayed, drawbacks including a drawback that an image streams take place. In an actual panel, therefore, for improving the response speed, the alignment film is not rubbed parallel to the electrodes but rubbed in a direction shifted by about 15°. However, even when the direction of rubbing is thus shifted, since the response time permitted by the IPS mode is twice longer than the one permitted by the TN mode, the response speed is very low. Moreover, when rubbing is carried out in the direction shifted by about 15°, a viewing angle characteristic of a panel does not become uniform between the right and left sides of the panel. Gray-scale reversal occurs relative to a specified viewing angle.

As mentioned above, the IPS mode that has been proposed as an alternative for solving the problem on the viewing angle characteristic of the TN mode has the problem that the characteristics offered by the IPS mode other than the viewing angle characteristic are insufficient. A vertically-aligned (VA) mode using a vertical alignment film has been proposed. The VA mode does not use a rotary polarization effect which is used in the TN mode, but uses a birefringent (double refraction) effect. The VA mode is a mode using a negative liquid crystal material and vertical alignment film. When no voltage is applied, liquid crystalline molecules are aligned in a vertical direction and black display appears. When a predetermined voltage is, applied, the liquid crystalline molecules are aligned in a horizontal direction and white display appears. A contrast in display offered by the VA mode is higher than that offered by the TN mode. A response speed is also higher, and an excellent viewing angle characteristic is provided for white display and black display. The VA mode is therefore attracting attention as a novel mode for a liquid crystal display.

However, the VA mode has the same problem as the TN mode concerning halftone display, that is, a problem that the light intensity of display varies depending on the viewing angle. The VA mode provides a much higher contrast than the TN mode and is superior to the TN mode in terms of a viewing angle characteristic concerning a viewing angle or a viewing angle characteristic, because even when no voltage is applied, liquid crystalline molecules near an alignment film are aligned nearly vertically. However, the VA mode is inferior to the IPS mode in terms of the viewing angle characteristic.

It is known that viewing angle performance of a liquid crystal display device (LCD) in the TN mode can be improved by setting the orientation directions of the liquid crystalline molecules inside pixels to a plurality of mutually different directions. Generally, the orientation direction of the liquid crystalline molecules (pre-tilt angles) which keep contact with a substrate surface in the TN mode are restricted by the direction of a rubbing treatment applied to the alignment film. The rubbing treatment is a processing which rubs the surface of the alignment film in one direction by a cloth such as rayon, and the liquid crystalline molecules are orientated in the rubbing direction. Therefore, viewing angle performance can be improved by making the rubbing direction different inside the pixels.

Though the rubbing treatment has gained a wide application, it is the treatment that rubs and consequently, damages, the surface of the alignment film and involves the problem that dust is likely to occur.

A method which forms a concavo-convex pattern on an electrode is known as another method of restricting the pre-tilt angle of the liquid crystalline molecules in the TN mode. The liquid crystalline molecules in the proximity of the electrodes are orientated along the surface having the concavo-convex pattern.

It is known that viewing angle performance of a liquid crystal display device in the VA mode can be improved by setting the orientation directions of the liquid crystalline molecules inside pixels to a plurality of mutually different directions. Japanese Unexamined Patent Publication (Kokai) No. 6-301036 discloses a LCD in which apertures are provided on a counter electrode. Each aperture faces a center of a pixel electrode and oblique electric fields are generated at a center of each pixel. The orientation directions of the liquid crystalline molecules inside each pixel are divided into two or four directions due to the oblique electric fields. However, the LCD disclosed in Japanese Unexamined Patent Publication (Kokai) No. 6-301036 has a problem that its response (switching) speed is not enough, particularly, a response speed for transition from a state in which no voltage is applied to a state in which a voltage is applied is slow. A cause of this problem is presumed that no oblique electric field exists when no voltage is applied between the electrodes. Further, because a length of each area having continuously oriented liquid crystalline molecules in each pixel is a half of a pixel size, a time for all liquid crystalline molecules in each area to be oriented in one direction becomes long.

Further, Japanese Unexamined Patent Publication (Kokai) No. 7-199193 discloses a VA LCD in which slopes having different directions are provided on electrodes and the orientation directions of the liquid crystalline molecules inside each pixel are divided. However, according to the disclosed constitutions, the vertical alignment film formed on the slopes are rubbed, therefore, the VA LCD disclosed in Japanese Unexamined Patent Publication (Kokai) No-7-199193 also has the above-mentioned problem that dust is likely to occur. Further, according to the disclosed constitutions, the size of the slopes is a half of the pixel, therefore, all liquid crystalline molecules faces the slopes are inclined, a good black display cannot be obtained. This causes a reduction of contrast. Further, inclination angles of the slopes are small because two or four slopes are provided across each pixel. It is found that the gentle slopes cannot fully define the orientation directions of the liquid crystalline molecules. In order to realize steep slopes, it is necessary to increase a thickness of a structure having slopes. However, when the thickness of the structure becomes large, charges accumulated on the structure becomes large. This causes a phenomenon that the liquid crystalline molecules do not change their orientations when a voltage is applied due to the accumulated charges. This phenomenon is so-called a burn.

SUMMARY OF THE INVENTION

As described above, there are some problems to realize a division of orientation directions of the liquid crystalline molecules for improving the viewing angle performance in the VA LCD.

An object of the present invention is to improve a viewing angle characteristic of a VA liquid crystal display, and to realize a VA liquid crystal display exhibiting a viewing angle characteristic that is as good as the one exhibited by the IPS mode or better than it while permitting the same contrast and operation speed as the conventional liquid crystal displays.

According to the present invention, in the VA mode employing a conventional vertical alignment film and adopting a negative liquid crystal as a liquid crystal material, a domain regulating means is included for regulating the orientation of a liquid crystal in which liquid crystalline molecules are aligned obliquely when a voltage is applied so that the orientation will include a plurality of directions within each pixel. The domain regulating means is provided on at least one of the substrates. Further, at least one of domain regulating means has inclined surfaces (slopes). The inclined surfaces include surfaces which are almost vertical to the substrates. Rubbing need not be performed on the vertical alignment film.

In the VA LCD device, when no voltage is applied, in almost all regions of the liquid crystal other than the protrusions, liquid crystalline molecules are aligned nearly vertically to the surfaces of the substrates. The liquid crystalline molecules near the inclined surfaces also orientates vertically to the inclined surfaces, therefore, the liquid crystalline molecules are inclined. When a voltage is applied, the liquid crystalline molecules tilt according to an electric field strength. Since the electric fields are vertical to the substrates, when a direction of tilt is not defined by carrying out rubbing, the azimuth in which the liquid crystalline molecules tilt due to the electric fields includes all directions of 360°. If there are pre-tilted liquid crystalline molecules, surrounding liquid crystalline molecules are tilted in the directions of the pre-tilted liquid crystalline molecules. Even when rubbing is not carried out, the directions in which the liquid crystalline molecules lying in gaps between the protrusions can be restricted to the azimuths of the liquid crystalline molecules in contact with the surfaces of the protrusions. When a voltage is increased, the negative liquid crystalline molecules are tilted in directions vertical to the electric fields.

As mentioned above, the inclined surfaces fill the role of a trigger for determining azimuths in which the liquid crystalline molecules are aligned with application of a voltage. The inclined surfaces need not have large area. With small inclined surfaces, when no voltage is applied, the liquid crystalline molecules in almost all the regions of the liquid-crystal layer except the inclined surfaces are aligned vertically to the surfaces of the substrates. This results in nearly perfect black display. Thus, a contrast can be raised.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be more clearly understood from the description as set below with reference to the accompanying drawings, wherein:

FIGS. **1**A and **1**B are diagrams for explaining a panel structure and an operational principle of a TN LCD;

FIGS. **2**A to **2**C are diagrams for explaining a change of viewing according to a change of viewing angle in the TN LCD;

FIGS. **3**A to **3**D are diagrams for explaining an IPS LCD;

FIG. **4** is a diagram giving a definition of a coordinate system employed in studying viewing of a liquid crystal display as an example of the IPS LCD;

FIG. **5** is a diagram showing a gray-scale reversal areas in the IPS LCD;

FIGS. **6**A and **6**B are diagrams showing examples of changes in display luminance levels of display in relation to the polar angle;

FIGS. **7**A to **7**C are diagrams for explaining a VA LCD and problems thereof;

FIGS. **8**A to **8**C are diagrams for explaining rubbing treatment;

FIGS. **9**A to **9**C are diagrams for explaining principles of the present invention;

FIGS. **10**A to **10**C are diagrams for explaining determination of an orientation by protrusions;

FIGS. **11**A to **11**C are diagrams showing examples of the protrusions;

FIGS. **12**A to **12**C are diagrams showing examples of realizing the domain regulating means;

FIG. **13** is a diagram showing overall configuration of a liquid crystal panel of the first embodiment;

FIGS. **14**A and **14**B are diagrams showing the structure of a panel in accordance with a first embodiment;

FIG. **15** is a diagram showing the relationship between a pattern of protrusions and pixels in the first embodiment;

FIG. **16** is a diagram showing the pattern of protrusions outside a display area of the first embodiment;

FIG. **17** is a sectional view of the LCD panel of the first embodiment;

FIGS. **18**A and **18**B are diagrams showing the position of a liquid-crystal injection port of the LCD panel of the first embodiment;

FIG. **19** is a diagram showing contours of protrusions in a prototype of the first embodiment defined by performing measurement using a tracer type coating thickness meter;

FIGS. **20**A and **20**B are diagrams indicating a change in response speed according to a change of spacing between protrusions in the panel of the first embodiment;

FIG. **21** is a diagram indicating a change in switching speed according to a change of spacing between protrusions in the panel of the first embodiment;

FIG. **22** is a diagram showing a viewing angle characteristic of the panel of the first embodiment;

FIGS. **23**A to **23**C are diagrams showing changes in display luminance levels of the panel of the first embodiment;

FIGS. **24**A and **24**B are diagrams showing changes in display luminance levels of the panel of the first embodiment;

FIG. **25** is a diagram showing a viewing angle characteristic of the panel of the first embodiment having a phase-difference film;

FIGS. **26**A to **26**C are diagrams showing changes in display luminance levels of the panel of the first embodiment having a phase-difference film;

FIG. **27** is a diagram for explaining occurrence of light leakage near the protrusions;

FIG. **28** is a diagram showing a change in transmittance according to a change of applied voltage;

FIG. **29** is a diagram showing a change in contrast ratio according to a change of applied voltage;

FIG. **30** is a diagram showing a change in transmittance of white display according to a change of height of protrusions in the panel of the first embodiment;

FIG. **31** is a diagram showing a change in transmittance of black display according to a change of height of protrusions in the panel of the first embodiment;

FIG. **32** is a diagram showing a change in contrast ratio according to a change of height of protrusions in the panel of the first embodiment;

FIG. **33** is a diagram showing a pattern of protrusions of the second embodiment;

FIG. **34** is a diagram showing a pattern of protrusions of a third embodiment;

FIG. **35** is a diagram showing a modification of the pattern of protrusions of the third embodiment;

FIG. **36** is a diagram showing an alignment of liquid crystalline molecules near apices of the protrusions;

FIGS. **37**A and **37**B are diagrams showing shapes of protrusions of a fourth embodiment; protrusions;

FIGS. **38**A and **38**B are diagrams showing a structure of a panel of a fifth embodiment;

FIG. **39** is a diagram showing a pattern of slits of a pixel electrode of the fifth embodiment;

FIG. **40** is a diagram showing an example of alignment of liquid crystalline molecules at a connection of slits;

FIG. **41** is a diagram showing generations of domains in the panel of the fifth embodiment;

FIG. **42** is a diagram showing shapes of protrusions and slits of a sixth embodiment;

FIG. **43** is a diagram showing generations of domains at corners of the protrusions and slits in the panel of the sixth embodiment;

FIG. **44** is a plan view of pixel portion in a LCD panel of the sixth embodiment;

FIG. **45** is a diagram showing a pattern of pixel electrodes of the sixth embodiment;

FIG. **46** is a sectional view of the LCD panel of the sixth embodiment;

FIG. **47** is a diagram showing a viewing angle characteristic of the panel of the sixth embodiment;

FIGS. **48**A to **48**C are diagrams showing changes in display luminance levels of the panel of the sixth embodiment;

FIGS. **49**A and **49**B are diagrams showing a modification of pattern of pixel electrodes of the sixth embodiment;

FIGS. **50**A and **50**B are diagrams showing a pattern of pixel electrodes and a structure of a panel of the seventh embodiment;

FIG. **51** is a plan view of pixel portion in a LCD panel of the seventh embodiment;

FIG. **52** is a diagram showing a structure of a panel of an eighth embodiment;

FIGS. **53**A to **53**J are diagrams showing a process for producing a TFT substrate of the eighth embodiment;

FIG. **54** is a diagram showing a pattern of protrusions a panel of a ninth embodiment;

FIG. **55** is a plan view of pixel portion in a LCD panel of the ninth embodiment;

FIG. **56** is a diagram showing a modification of pattern of protrusions of the ninth embodiment;

FIGS. **57**A and **57**B are diagrams for explaining influences of oblique electric fields at edges of an electrode;

FIG. **58** is a diagram for explaining a problem occurred in a structure using zigzag protrusions;

FIG. **59** is a diagram showing in enlarged form the neighborhood of a portion where a schlieren structure is observed;

FIG. **60** is a diagram showing a region where response speed are reduced;

FIGS. **61**A and **61**B are sectional views of the portions where the response speed is reduced;

FIGS. **62**A and **62**B are diagrams showing a fundamental arrangement of a protrusion with respect to an edge of pixel electrode in a tenth embodiment;

FIG. **63** is a diagram showing an arrangement of protrusions in the tenth embodiment;

FIG. **64** is a detailed diagram showing a distinctive portion of the tenth embodiment;

FIGS. **65**A and **65**B are diagrams for explaining a change in orientation direction by irradiation of ultraviolet light;

FIG. **66** is a diagram showing a modification of the tenth embodiment;

FIGS. **67**A to **67**C are diagrams for explaining desirable arrangements of the protrusions and an edge of the pixel electrode;

FIG. **68** is a diagram for explaining desirable arrangements of the depressions and an edge of the pixel electrode;

FIGS. **69**A and **69**B are diagrams showing desirable arrangements of the protrusions and edges of the pixel electrode;

FIGS. **70**A and **70**B are diagrams showing a pattern of protrusions of a eleventh embodiment;

FIG. **71** is a diagram showing an example in which discontinuous protrusions are provided in each pixel;

FIG. **72** is a diagram showing shapes of the pixel electrodes and protrusions of a twelfth embodiment;

FIG. **73** is a diagram showing a modification of shapes of the pixel electrodes and protrusions of a twelfth embodiment;

FIG. **74** is a diagram showing a modification of shapes of the pixel electrodes and protrusions of a twelfth embodiment;

FIG. **75** is a diagram showing a pattern of protrusions of a thirteenth embodiment;

FIGS. **76**A and **76**B are sectional views of the third embodiment;

FIGS. **77**A and **77**B are diagrams showing an operation of a storage capacitor (CS) and a structure of electrodes;

FIGS. **78**A and **78**B are diagrams showing an arrangement of protrusions and CS electrodes of a fourteenth embodiment;

FIGS. **79**A and **79**B are diagrams showing an arrangement of slits and CS electrodes of a modification of the fourteenth embodiment;

FIGS. **80**A and **80**B are diagrams showing an arrangement of protrusions and CS electrodes of an another modification of the fourteenth embodiment;

FIGS. **81**A and **81**B are diagrams showing an arrangement of protrusions and CS electrodes of an another modification of the fourteenth embodiment;

FIG. **82** is a diagram showing a pattern of protrusions of the fifteenth embodiment;

FIGS. **83**A to **83**D are diagrams for explaining alignment changes of the liquid crystalline molecules in the fifteenth embodiment;

FIG. **84** is a diagram showing a viewing angle characteristic of the panel of the fifteenth embodiment;

FIGS. **85**A to **85**D are diagrams showing changes of response times between gray-scale levels in the fifteenth embodiment, TN LCD, and other VA LCDs;

FIGS. **86**A and **86**B are diagrams showing an arrangement of protrusions of a modification of the fifteenth embodiment;

FIG. **87** is a diagram showing an arrangement of protrusions of another modification of the fifteenth embodiment;

FIG. **88** is a diagram showing an arrangement of protrusions of another modification of the fifteenth embodiment;

FIG. **89** is a diagram showing an arrangement of protrusions of another modification of the fifteenth embodiment;

FIGS. **90**A and **90**B are diagrams showing a structure of protrusions of a sixteenth embodiment;

FIG. **91** is a diagram showing an arrangement of protrusions of the sixteenth embodiment;

FIGS. **92**A and **92**B are diagrams showing a structure of a panel of a seventeenth embodiment;

FIG. **93** is a diagram showing a structure of a panel of a eighteenth embodiment;

FIG. **94** is a diagram showing a structure of a panel of a nineteenth embodiment;

FIG. **95** is a diagram showing a structure of a panel of a twentieth embodiment;

FIG. **96** is a diagram showing a structure of a panel of a modification of the twentieth embodiment;

FIG. **97** is a diagram showing a structure of a panel of another modification of the twentieth embodiment;

FIG. **98** is a diagram showing a structure of a panel of another modification of the twentieth embodiment;

FIGS. **99**A and **99**B are diagrams showing a structure of a panel of a 21st embodiment;

FIGS. **100**A and **100**B are diagrams for explaining an influence of an assembly error to the alignment division;

FIGS. **101**A and **101**B are diagrams showing a structure of a panel of a 22nd embodiment;

FIG. **102** is a diagram showing a structure of a panel of a 23rd embodiment;

FIGS. **103**A and **103**B are diagrams showing a structure of a panel of a 24th embodiment;

FIG. **104** is a diagram showing a pattern of protrusions to which the structure of the 24th embodiment is applied;

FIGS. **105**A and **105**B are diagrams showing a structure of a panel of a 25th embodiment;

FIG. **106** is a diagram showing a structure of a panel in which a relationship of response time with respect to a gap length between protrusions is measured;

FIG. **107** is a diagram showing the relationship of response time with respect to the gap length;

FIGS. **108**A and **108**B are diagrams showing a relationship of a transmittance with respect to a gap between protrusions;

FIGS. **109**A and **109**B are diagrams showing an operational principle of the 25th embodiment;

FIG. **110** is a diagram showing a structure of a panel of a 26th embodiment;

FIG. **111** is a diagram showing a viewing angle characteristic of the panel of the 26th embodiment;

FIG. **112** is a diagram showing a pattern of protrusions of normal types;

FIG. **113** is a diagram showing wavelength dispersion characteristic of the optical anisotropy of the liquid crystal;

FIG. **114** is a diagram showing a pattern of protrusions of a 27th embodiment;

FIG. **115** is a diagram showing a relation between an applied voltage and transmittance;

FIG. **116** is a diagram showing a pattern of protrusions of a 28th embodiment;

FIG. **117** is a diagram showing a pattern of protrusions of a 29th embodiment;

FIG. **118** is a diagram showing a pixel structure of the 29th embodiment;

FIG. **119** is a diagram showing shapes of protrusions of a 30th embodiment;

FIG. **120** is a diagram showing a change of transmittance according to a change of height of protrusions;

FIG. **121** is a diagram showing a change of a contrast ratio according to a change of height of protrusions;

FIG. **122** is a diagram showing a change of transmittance in white level according to a change of height of protrusions;

FIG. **123** is a diagram showing a change of transmittance in black level according to a change of height of protrusions;

FIGS. **124**A and **124**B are diagrams showing pixel structures of an modification of the 30th embodiment;

FIGS. **125**A and **125**B are diagrams showing shapes of protrusions of a 31st embodiment;

FIG. **126** is a diagram showing a relationship between a twisted angle and a thickness of liquid crystal layer in a panel of the VA LCD;

FIG. **127** is a diagram showing a relationship between a relative luminance of white level and a retardation of liquid crystal in the panels of the VA LCD and TN LCD;

FIG. **128** is a diagram showing relationships between transmittances and a retardation of liquid crystal at respective wavelengths in the panel of the VA LCD;

FIG. **129** is a diagram showing relationships between response times and a gap between protrusions at respective wavelengths in the panel of the VA LCD;

FIG. **130** is a diagram showing relationships between an aperture ratio and a gap between protrusions at respective wavelengths in the panel of the VA LCD;

FIG. **131** is a diagram showing a structure of a panel of a 32nd embodiment;

FIG. **132** is a diagram showing a structure of a panel of a modification of the 32nd embodiment;

FIG. **133** is a diagram showing a structure of a TFT substrate of a 33rd embodiment;

FIGS. **134**A and **134**B are diagrams showing a pattern of protrusions of the 33rd embodiment;

FIG. **135** is a diagram showing a structure of a panel of a 34th embodiment;

FIGS. **136**A and **136**B are diagrams showing a pattern of protrusions of the 34th embodiment;

FIGS. **137**A to **137**D are diagrams showing a process for producing a TFT substrate of the 35th embodiment;

FIG. **138** is a diagram showing a structure of a TFT substrate of the 35th embodiment;

FIGS. **139**A to **139**E are diagrams showing a process for producing a TFT substrate of the 36th embodiment;

FIGS. **140**A and **140**B are diagrams for explaining a problem of dielectric substance on an electrode;

FIGS. **141**A and **141**B are diagrams showing a structure of protrusions of a 37th embodiment;

FIGS. **142**A to **142**E are diagrams showing a process for producing protrusions of the 37th embodiment;

FIG. **143** is a diagram showing a structure of protrusions of a 38th embodiment;

FIGS. **144**A and **144**B are diagrams showing a change of a shape of a protrusion due to baking;

FIGS. **145**A to **145**E are diagrams showing a change of the shape of the protrusion according to baking temperatures;

FIGS. **146**A to **146**C are diagrams showing a change of the shape of the protrusion according to a width of the protrusion;

FIGS. **147**A and **147**B are diagrams showing protrusions and a forming condition of the vertical alignment film;

FIGS. **148**A to **148**C are diagrams showing an example of a method of forming protrusions according to a 39th embodiment;

FIGS. **149**A and **148**B are diagrams showing an another example of a method of forming protrusions according to the 39th embodiment;

FIG. **150** is a diagram showing an another example of a method of forming protrusions according to the 39th embodiment;

FIGS. **151**A and **151**B are diagrams showing changes of a repellent occurrence ratio according to the ultraviolet light irradiation;

FIGS. **152**A to **152**C are diagrams showing an another example of a method of forming protrusions according to the 39th embodiment;

FIGS. **153**A to **153**C are diagrams showing an another example of a method of forming protrusions according to the 39th embodiment;

FIGS. **154**A and **154**B are diagrams showing an another example of a method of forming protrusions according to the 39th embodiment;

FIGS. **155**A and **155**B are diagrams showing an another example of a method of forming protrusions according to the 39th embodiment;

FIG. **156** is a diagram showing a temperature condition of the method shown in FIGS. **155**A and **155**B;

FIGS. **157**A to **157**C are diagrams showing an another example of a method of forming protrusions according to the 39th embodiment;

FIG. **158** is a diagram showing a structure of a panel of a prior art provided with black matrices;

FIG. **159** is a diagram showing a structure of a panel of a 40th embodiment;

FIG. **160** is a diagram showing a pattern of protrusions of the 40th embodiment;

FIG. **161** is a diagram showing a shade pattern (black matrices) of a 41th embodiment;

FIG. **162** is a sectional view of a panel of the 41st embodiment;

FIG. **163** is a diagram showing pixels and a pattern of protrusions of a 42nd embodiment;

FIG. **164** is a diagram showing a structure of a prior art panel having spacers;

FIGS. **165**A and **165**B are diagrams showing structures of panels of a 43rd embodiment and an modification thereof;

FIGS. **166**A and **166**B are diagrams showing structures of panels of modifications of the 43rd embodiment;

FIG. **167** is a diagram showing a structure of a panel of a modification of the 43rd embodiment;

FIGS. **168**A to **168**C are diagrams showing a process of a panel of a 44th embodiment;

FIG. **169** is a diagram showing a relationship between a scattered density of spacers and a cell gap in the 44th embodiment;

FIG. **170** is a diagram showing a relationship between a scattered density of spacers and generations of blemishes when a force is applied to the panel;

FIGS. **171**A and **171**B are diagrams showing chemical formulas of crown added to protrusion materials so that the protrusions have ion absorption ability;

FIGS. **172**A and **172**B are diagrams showing chemical formulas of kryptand added to protrusion materials so that the protrusions have ion absorption ability;

FIGS. **173**A and **173**B are diagrams showing structures of CF substrates of a 45th embodiment and a modification thereof;

FIG. **174** is a diagram showing a structure of a panel of a 46th embodiment;

FIGS. **175**A and **175**B are diagrams showing structures of CF substrates of another modifications of the 46th embodiment;

FIGS. **176**A and **176**B are diagrams showing structures of CF substrates of another modifications of the 46th embodiment;

FIGS. **177**A and **177**B are diagrams showing structures of CF substrates of another modifications of the 46th embodiment;

FIG. **178** is a diagram showing a structure of a panel of an another modification of the 46th embodiment;

FIGS. **179**A and **179**B are diagrams showing structures of CF substrates of another modifications of the 46th embodiment;

FIGS. **180**A and **180**B are diagrams showing structures of CF substrates of another modifications of the 46th embodiment;

FIGS. **181**A to **181**G are diagrams showing a process for forming protrusions on the CF substrate according to a 47th embodiment;

FIG. **182** is a diagram showing a structure of a panel of the 47th embodiment;

FIGS. **183**A and **183**B are diagrams showing a process for forming black matrices of the CF substrate according to a 48th embodiment;

FIGS. **184**A and **184**B are diagrams showing a structure of a panel of the 48th embodiment;

FIGS. **185**A to **185**C are diagrams showing a process for forming protrusions on the CF substrate according to a 49th embodiment;

FIG. **186** is a diagram showing a structure of a panel of the 49th embodiment;

FIG. **187** is a diagram showing a process for forming protrusions on the CF substrate according to a 50th embodiment;

FIGS. **188**A and **188**B are diagrams showing a structure of a panel of the 50th embodiment;

FIG. **189** is a diagram showing a structure of a CF substrate of a 51th embodiment;

FIGS. **190**A and **190**B are diagrams showing structures of CF substrates of modifications of the 51th embodiment;

FIG. **191** is a diagram showing structures of CF substrates of modifications of the 51th embodiment;

FIG. **192** is a diagram showing structures of CF substrates of modifications of the 51th embodiment;

FIG. **193** is a diagram showing a structure of a panel of an another modification of the 50th embodiment;

FIG. **194** is a diagram showing an example of a product employing the LCD in accordance with the present invention;

FIG. **195** is a diagram showing a structure of the product shown in FIG. **197**;

FIGS. **196**A and **196**B are diagrams showing examples of arrangements of the protrusions in the product;

FIG. **197** is a flowchart showing a process of a panel according to the present invention;

FIG. **198** is a flowchart showing a process of forming protrusions;

FIG. **199** is a diagram for explaining a process of forming protrusions by printing;

FIG. **200** is a diagram showing the configuration of a liquid-crystal injection apparatus;

FIGS. **201**A and **201**B are diagrams showing examples of the positions of liquid-crystal injection ports of the LCD panel;

FIGS. **202**A and **202**B are diagrams showing examples of the positions of liquid-crystal injection ports of the LCD panel;

FIGS. **203**A and **203**B are diagrams showing examples of the positions of liquid-crystal injection ports of the LCD panel;

FIG. **204** is a diagram showing a structure of electrodes near the liquid-crystal injection port in the panel of the present invention;

FIGS. **205**A to **205**C are diagrams for explaining a defect due to contamination by polyurethane resin and skin in the VA LCD;

FIG. **206** is a diagram showing a relationship between a size of polyurethane resin particulate and a size of defective area;

FIG. **207** is a diagram showing a simulation result of a relationship between a display frequency and an effective voltage at respective specific resistances;

FIG. **208** is a diagram showing a simulation result of a discharge time at respective specific resistances;

FIG. **209** is a diagram showing a simulation result of a discharge time at respective specific resistances;

FIG. **210** is a diagram showing a fundamental constitution of the prior art VA LCD;

FIG. **211** is a diagram showing a viewing angle characteristic (contrast ratio) of the prior art VA LCD;

FIG. **212** is a diagram showing a viewing angle characteristic (gray-scale reversal) of the prior art VA LCD;

FIG. **213** is a diagram showing a fundamental constitution of the panel of according to the present invention;

FIG. **214** is a diagram showing a viewing angle characteristic (contrast ratio) of present invention;

FIG. **215** is a diagram showing a viewing angle characteristic (gray-scale reversal) of present invention;

FIG. **216** is a diagram for explaining characteristics of a retardation film;

FIG. **217** is a diagram showing a constitution of a panel of a 52nd embodiment;

FIG. **218** is a diagram showing a viewing angle characteristic (gray-scale reversal) of the 52nd embodiment;

FIG. **219** is a diagram showing a viewing angle characteristic (gray-scale reversal) of the 52nd embodiment;

FIG. **220** is a diagram showing a relationship of a polar angle at which a predetermined value of contrast can be obtained with respect to a retardation in the 52nd embodiment;

FIG. **221** is a diagram showing a constitution of a panel of a 53rd embodiment;

FIG. **222** is a diagram showing a viewing angle characteristic (gray-scale reversal) of the 52rd embodiment;

FIG. **223** is a diagram showing a viewing angle characteristic (gray-scale reversal) of the 52rd embodiment;

FIG. **224** is a diagram showing a relationship of a polar angle at which a predetermined value of contrast can be obtained with respect to a retardation in the 53rd embodiment;

FIG. **225** is a diagram showing a constitution of a panel of a 54th embodiment;

FIG. **226** is a diagram showing a relationship of a polar angle at which a predetermined value of contrast can be obtained with respect to a retardation in the 54th embodiment;

FIG. **227** is a diagram showing a change of an upper limit to the optimum condition regarding contrast with respect to a retardation in the 54th embodiment;

FIG. **228** is a diagram showing a change of a polar angle at which no gray-scale reversal is generated with respect to a retardation in the 54th embodiment;

FIG. **229** is a diagram showing a change of an upper limit to the optimum condition regarding gray-scale reversal with respect to a retardation in the 54th embodiment;

FIG. **230** is a diagram showing a viewing angle characteristic (gray-scale reversal) of the 55th embodiment;

FIG. **231** is a diagram showing a viewing angle characteristic (gray-scale reversal) of the 55th embodiment;

FIG. **232** is a diagram showing a constitution of a panel of a 56th embodiment;

FIG. **233** is a diagram showing a viewing angle characteristic (gray-scale reversal) of the 56th embodiment;

FIG. **234** is a diagram showing a viewing angle characteristic (gray-scale reversal) of the 56th embodiment;

FIG. **235** is a diagram showing a relationship of a polar angle at which a predetermined value of contrast can be obtained with respect to a retardation in the 56th embodiment;

FIG. **236** is a diagram showing a constitution of a panel of a 57th embodiment;

FIG. **237** is a diagram showing a viewing angle characteristic (gray-scale reversal) of the 57th embodiment;

FIG. **238** is a diagram showing a viewing angle characteristic (gray-scale reversal) of the 57th embodiment;

FIG. **239** is a diagram showing a relationship of a polar angle at which a predetermined value of contrast can be obtained with respect to a retardation in the 57th embodiment;

FIG. **240** is a diagram showing a constitution of a panel of a 58th embodiment;

FIG. **241** is a diagram showing a viewing angle characteristic (gray-scale reversal) of the 58th embodiment;

FIG. **242** is a diagram showing a viewing angle characteristic (gray-scale reversal) of the 58th embodiment;

FIG. **243** is a diagram showing a relationship of a polar angle at which a predetermined value of contrast can be obtained with respect to a retardation in the 58th embodiment;

FIG. **244** is a diagram showing a constitution of a panel of a 59th embodiment;

FIG. **245** is a diagram showing a viewing angle characteristic (gray-scale reversal) of the 59th embodiment;

FIG. **246** is a diagram showing a viewing angle characteristic (gray-scale reversal) of the 59th embodiment;

FIG. **247** is a diagram showing a relationship of a polar angle at which a predetermined value of contrast can be obtained with respect to a retardation in the 59th embodiment;

FIG. **248** is a diagram showing a change of an upper limit to the optimum condition regarding contrast with respect to a retardation in the 59th embodiment;

FIG. **249** is a diagram showing a viewing angle characteristic of a panel of the 32th embodiment;

FIG. **250** is a diagram showing a change of an ion density when an ion absorption treatment is applied to the protrusions;

FIGS. **251**A to **251**D are diagrams showing a process of a method of a panel of a modification in the 51st embodiment;

FIGS. **252**A and **252**B are diagrams showing a pattern of protrusions and a sectional structure of the panel of the second embodiment;

FIG. **253** is a diagram showing a pattern of protrusions of an another modification of the second embodiment;

FIGS. **254**A and **254**B are diagrams showing a pattern of protrusions and a sectional structure of the panel of the sixteenth embodiment;

FIG. **255** is a detailed diagram showing a distinctive portion of a modification of the tenth embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Before proceeding to a detailed description of the preferred embodiments of the present invention, a prior art liquid crystal display device will be described to allow a clearer understanding of the differences between the present invention and the prior art.

FIGS. **1**A and **1**B are diagrams for explaining the structure and principles of operation of a panel of the TN LCD. As shown in FIGS. **1**A and **1**B, an alignment film is placed on transparent electrodes **12** and **13** formed on glass substrates, a rubbing treatment is performed so that orientation directions of the liquid crystalline molecules on the two substrates are shifted by 90° to each other, and a TN liquid crystal is sandwiched between the transparent electrodes. Due to the properties of the liquid crystal, liquid crystalline molecules in contact with the alignment films are aligned in the directions of the orientation defined by the alignment films. The other liquid crystalline molecules are aligned in line with the aligned molecules. Consequently, as shown in FIG. **1**A, the liquid crystalline molecules are aligned while twisted by 90°. Two sheet polarizers **11** and **15** are located in parallel with the directions of the orientation defined by the alignment films.

When light **10** that is not polarized falls on a panel having the foregoing structure, the light passing through the sheet polarizer **11** becomes linearly-polarized light and enters the liquid crystal. Since the liquid crystalline molecules are aligned while twisted 90°, the incident light is passed while twisted 90°. The light can therefore pass through the lower sheet polarizer **15**. This state is a bright state.

Next, as shown in FIG. **1**B, when a voltage is applied to the electrodes **12** and **13** and thus applied to the liquid crystalline molecules, the liquid crystalline molecules erect themselves to untwist. However, on the surfaces of the alignment films, since an orientation control force is stronger, the orientation of the liquid crystal remains matched with the orientation defined by the alignment films. In this state, the liquid crystalline molecules are isotropic relative to passing light. The linearly-polarized light incident on the liquid-crystal layer will therefore not turn the direction of polarization. The linearly-polarized light passing through the upper sheet polarizer **11** cannot therefore pass through the lower sheet polarizer **15**. This brings about a dark state. Thereafter, when a state in which no voltage is applied is resumed, display is returned to the bright state owing to the orientation control force.

The technology of manufacturing the TN TFT LCD has outstandingly advanced in recent years. Contrast and color reproducibility provided by the TN TFT LCD have surpassed those offered by the CRT. However, the TN LCD has a critical drawback of a narrow viewing angle range. This poses a problem that the application of the TN LCD is limited. FIGS. **2**A to **2**C are diagrams for explaining this problem. FIG. **2**A shows a state of white display in which no voltage is applied, FIG. **2**B shows a state of halftone display in which an intermediate voltage is applied, and FIG. **2**C shows a state of black display in which a predetermined voltage is applied. As shown in FIG. **2**A, in the state in which no voltage is applied, liquid crystalline molecules are aligned in the same direction with a slight inclination (about 10 to 50). In reality, the molecules are twisted as shown in FIG. **1**A. For convenience' sake, the molecules are illustrated like FIG. **2**A. In this state, light is seen nearly white in any azimuth. Moreover, as shown in FIG. **2**C, in the state in which a voltage is applied, intermediate liquid crystalline molecules except those located near the alignment films are aligned in a vertical direction. Incident linearly-polarized light is therefore seen black but not twisted. At this time, light obliquely incident on a screen (panel) has the direction of polarization thereof twisted to some extent because it passes obliquely through the liquid crystalline molecules aligned in the vertical direction. The light is therefore seen halftone (gray) but not perfect black. As shown in FIG. **2**B, in the state in which an intermediate voltage lower than the voltage applied in the state shown in FIG. **2**C is applied, the liquid crystalline molecules near the alignment films are aligned in a horizontal direction but the liquid crystalline molecules in the middle parts of cells erect themselves halfway. The birefringent property of the liquid crystal is lost to some extent. This causes a transmittance to deteriorate and brings about halftone (gray) display. However, this refers only to light incident perpendicularly or the liquid-crystal panel. Obliquely incident light is seen differently, that is, light is seen differently depending on whether it is seen from the left or right side of the drawing. As illustrated, the liquid crystalline molecules are aligned mutually parallel relative to light propagating from right below to left above. The liquid crystal hardly exerts a birefringent effect. Therefore, when the panel is seen from left, it is seen black. By contrast, the liquid crystalline molecules are aligned vertically relative to light propagating from left below to right above. The liquid crystal exerts a great birefringent effect relative to incident light, and the incident light is twisted. This results in nearly white display. Thus, the most critical drawback of the TN LCD is that the display state varies depending on the viewing angle.

In an effort to solve the above problem, Japanese Examined Patent Publication (Kokai) Nos. 53-48452 and 1-120528 have proposed an LCD adopting a mode referred to as an IPS mode. FIGS. **3**A to **3**D are diagrams for explaining the IPS LCD. FIG. **3**A is a side view of the LCD with no voltage applied, FIG. **3**B is a top view thereof with no voltage applied, FIG. **3**C is a side view thereof with a voltage applied, and FIG. **3**D is a top view with a voltage

applied. In the IPS mode, as shown in FIGS. **3**A to **3**D, slit-like electrodes **18** and **19** are formed in one substrate **17**, and liquid crystalline molecules existent in a gap between the slit-like electrodes are driven with electric fields induced by a transverse electric wave. A material exhibiting positive dielectric anisotropy is used to make a liquid crystal **14**. When no electric field is applied, an alignment film is rubbed in order to align the liquid crystalline molecules homogeneously so that the major axes of the liquid crystalline molecules will be nearly parallel to the longitudinal direction of the electrodes **18** and **19**. In the illustrated example, the liquid crystalline molecules are homogeneously aligned with an azimuth of 15° relative to the longitudinal direction of the slit-like electrodes in order to make a direction (direction of turn), to which the orientation of the liquid crystal is changed with application of a voltage, constant. In this state, when a voltage is applied to the slit-like electrodes, as shown in FIG. **3**C, liquid crystalline molecules existent near the slit-like electrodes change their orientation so that the major axes thereof will be turned 90° relative to the longitudinal direction of the slit-like electrodes. However, since the other substrate **16** is orientationally processed so that liquid crystalline molecules will be aligned with an azimuth of 15° relative to the longitudinal direction of the slit-like electrodes, liquid crystalline molecules near the substrate **16** are aligned so that the major axes thereof will be nearly parallel to the longitudinal direction of the electrodes **18** and **19**. The liquid crystalline molecules are therefore aligned while twisted from the upper substrate **16** to the lower substrate **17**. In this kind of liquid crystal display, when the sheet polarizers **11** and **15** are placed on and under the substrates **16** and **17** respectively so that the axes of transmission thereof will be orthogonal to each other. When the axis of transmission of one sheet polarizer is made parallel to the major axes of the liquid crystalline molecules, black display can be attained with no voltage applied, and white display can be attained with a voltage applied.

As mentioned above, the IPS mode is characterized in that the liquid crystalline molecules do not erect themselves but turned in a transverse direction. In the TN mode or the like, when the liquid crystalline molecules erect themselves, the birefringent property of the liquid crystal varies depending on a direction of an viewing angle and a problem occurs. When the liquid crystalline molecules are turned in the transverse direction, the birefringent property hardly varies depending on a direction. This results in very good viewing angle characteristics. However, the IPS mode has another problems. One of the problems is that a response speed is quite low. The reason why the response speed is low is that although a gap between electrodes in the normal TN mode in which liquid crystalline molecules are turned is 5 micrometers, the gap in the IPS mode is 10 micrometers or more. The response speed can be raised by narrowing the gap between the electrodes. However, since electric fields of opposite polarities must be applied to the adjoining electrodes in the IPS mode, when the gap between the electrodes is narrowed, a short circuit occurs to bring about a display defect. For this reason, the gap between the electrodes cannot be narrowed very much. Besides, when the gap between the electrodes is narrowed, the ratio in area of the electrodes to display gets large. This poses a problem that a transmittance cannot be improved.

As mentioned above, the IPS mode suffers from slow switching. At present, when a motion picture representing a fast motion is displayed, drawbacks including a drawback that an image streams take place. In an actual panel, therefore, for improving the response speed, as shown in FIGS. **3**B and **3**D, the alignment film is not rubbed parallel to the electrodes but rubbed in a direction shifted by about 15°. For realizing horizontal alignment, when an agent is merely applied to the alignment film, liquid crystalline molecules are arrayed freely leftward or rightward and cannot be aligned in a predetermined direction. Rubbing is therefore carried out for rubbing the surface of the alignment film in a certain direction so that the liquid crystalline molecules will be aligned in the predetermined direction. When rubbing is carried out in the IPS mode, if rubbing proceeds parallel to the electrodes, liquid crystalline molecules near the center in the gap between the electrodes are slow to turn to the left or right with application of a voltage, and therefore slow to respond to the application. Rubbing is therefore, as shown in FIGS. **3**B and **3**D, carried out in a direction shifted by about 15° in order to demolish right-and-left uniformity. However, even when the direction of rubbing is thus shifted, since the response time permitted by the IPS mode is twice longer than the one permitted by the TN mode, the response speed is very low. Moreover, when rubbing is carried out in the direction shifted by about 15°, a viewing angle characteristic of a panel does not become uniform between the right and left sides of the panel. Gray-scale reversal occurs relative to a specified angle of a viewing angle range. This problem will be described with reference to FIGS. **4** to **6**B.

FIG. **4** is a diagram giving a definition of a coordinate system employed in studying viewing of a liquid crystal display (of the IPS type herein). As illustrated, a polar angle θ and azimuth ϕ are defined in relation to substrates **16** and **17**, electrodes **18** and **19**, and a liquid crystalline molecule **4**. FIG. **5** is a diagram showing a gray-scale reversal characteristic of a panel concerning a viewing angle. A gray scale from white to black is segmented into 8 gray-scale levels. Domain areas causing gray-scale reversal when a change in luminance is examined by varying the polar angle θ and azimuth ϕ are shown in FIG. **5**. In the drawing, reversal occurs at fours hatched areas. FIGS. **6**A and **6**B are diagrams showing examples of changes in luminance of display of 8 gray-scale levels in relation to the polar angle θ with the azimuths fixed to values of 75° and 135° causing reversal. White gray-scale reversal occurs at gray-scale levels associated with high luminances, that is, when white luminance deteriorates with an increasing value of the polar angle θ. Black gray-scale reversal occurs when black luminance increases with an increasing value of the polar angle θ. As mentioned, the IPS mode has a problem that gray-scale reversal occurs in four azimuths. Furthermore, the IPS mode has a problem that it is harder to manufacture the IPS LCD than the TN LCD. Thus, in the IPS mode, any of the other characteristics such as a transmittance, a response speed and productivity, is sacrificed for the viewing angle characteristic.

As mentioned above, the IPS mode that has been proposed as an alternative for solving the problem on the viewing angle characteristic of the TN mode has the problem that the characteristics offered by the IPS mode other than the viewing angle characteristic are insufficient. A vertically-aligned (VA) mode using a vertical alignment film has been proposed. FIGS. **7**A to **7**C are diagrams for explaining the VA mode. The VA mode is a mode using a negative liquid crystal material and vertical alignment film. As shown in FIG. **7**A, when no voltage is applied, liquid crystalline molecules are aligned in a vertical direction and black display appears. As shown in FIG. **7**C, when a predetermined voltage is applied, the liquid crystalline molecules are aligned in a horizontal direction and white display appears. A contrast in display offered by the VA mode is higher than

that offered by the TN mode. A response speed at black level is also higher. The VA mode is therefore attracting attention as a novel mode for a liquid crystal display.

However, the VA mode has the same problem as the TN mode concerning halftone display, that is, a problem that the display state varies depending on the viewing angle. For displaying a halftone in the VA mode, a voltage lower than a voltage to be applied for white display is applied. In this case, as shown in FIG. **7**B, liquid crystalline molecules are aligned in an oblique direction. As illustrated, the liquid crystalline molecules are aligned parallel to light propagating from right below point to left above. The liquid crystal is therefore seen black when viewed from the left side thereof because a birefringent effect is hardly exerted on the left side thereof. By contrast, the liquid crystalline molecules are aligned vertically to light propagating from left below to right above. The liquid crystal exerts a great birefringent effect relative to incident light, therefore, display becomes nearly white. Thus, there is the problem that the luminance varies depending the viewing angle. The VA mode provides a much higher contrast than the TN mode and is superior to the TN mode in terms of a viewing angle characteristic, because even when no voltage is applied, liquid crystalline molecules near an alignment film are aligned nearly vertically. However, the VA mode is not certainly superior to the IPS mode in terms of the viewing angle characteristic.

It is known that viewing angle performance of a liquid crystal display device (LCD) in the TN made can, be improved by setting the orientation directions of the liquid crystalline molecules inside pixels to a plurality of mutually different directions. Generally, the orientation direction of the liquid crystalline molecules (pre-tilt angles) which keep contact with a substrate surface in the TN mode are restricted by the direction of a rubbing treatment applied to the alignment film. The rubbing treatment is a processing which rubs the surface of the alignment film in one direction by a cloth such as rayon, and the liquid crystalline molecules are orientated in the rubbing direction. Therefore, viewing angle performance can be improved by making the rubbing direction different inside the pixels. FIGS. **8**A to **8**C show a method of making the rubbing direction different inside the pixels. As shown in this drawing, an alignment film **22** is formed on a glass substrate **16** (whose electrodes, etc., are omitted from the drawing). This alignment film **22** is then bought into contact with a rotating rubbing roll **201** to execute the rubbing treatment in one direction. Next, a photo-resist is applied to the alignment film **22** and a predetermined pattern is exposed and developed by photolithography. As a result, a layer **202** of the photo-resist which is patterned is formed as shown in the drawing. Next, the alignment film **22** is brought into contact with a rubbing roll **201** that is rotating to the opposite direction to the above so that only the open portions of the pattern are rubbed. In this way, a plurality of regions that are subjected to the rubbing treatment in different directions are formed inside the pixel, and the orientation directions of the liquid crystal become plural inside the pixel. Incidentally, the rubbing treatment can be done in arbitrarily different directions when the alignment film **22** is rotated relative to the rubbing roll **201**.

Though the rubbing treatment has gained a wide application, it is the treatment that rubs and consequently, damages, the surface of the alignment film and involves the problem that dust is likely to occur.

A method which forms a concavo-convex pattern on an electrode is known as another method of restricting the pre-tilt angle of the liquid crystalline molecules in the TN mode. The liquid crystalline molecules in the proximity of the electrodes are orientated along the surface having the concavo-convex pattern.

FIGS. **9**A to **9**C are diagrams for explaining the principles of the present invention. According to the present invention, as shown in FIGS. **9**A to **9**C, in the VA mode employing a conventional vertical alignment film and adopting a negative liquid crystal as a liquid crystal material, a domain regulating means is included for regulating the orientation of a liquid crystal in which liquid crystalline molecules are aligned obliquely when a voltage is applied so that the orientation will-include a plurality of directions within each pixel. In FIGS. **9**A to **9**C, as the domain regulating means, electrodes **12** on an upper substrate are slitted and associated with pixels, and an electrode **13** on a lower substrate is provided with protrusions (projections) **20**.

As shown in FIG. **9**A, in a state in which no voltage is applied, liquid crystalline molecules are aligned vertically to the surfaces of the substrates. When an intermediate voltage is applied, as shown in FIG. **9**B, electric fields oblique to the surfaces of the substrates are produced near the slits of the electrodes (edges of the electrodes). Moreover, liquid crystalline molecules near the protrusions **20** slightly tilt relative to their state attained with no voltage applied. The inclined surfaces of the protrusions and the oblique electric fields determine the directions in which the liquid crystalline molecules are tilted. The orientation of the liquid crystal is divided into different directions along a plane defined by each pair of protrusions **20** and the center of each slit. At this time, for example, light transmitted from immediately below to immediately above is affected by weak birefringence because the liquid crystalline molecules are slightly tilting.

Consequently, the transmission of light is suppressed and halftone display of gray appears. Light transmitted from right above to left below is hardly transmitted by a region of the liquid crystal in which liquid crystalline molecules are tilting leftward, while the light is quite readily transmitted by a region thereof in which liquid crystalline molecules are tilting rightward. On the average, halftone display of gray appears. Light transmitted from left below to right above contributes to gray display due to the same principles. Consequently, homogeneous display can be attained in all azimuths. Furthermore, when a predetermined voltage is applied, liquid crystalline molecules become nearly horizontal as shown in FIG. **9**C. White display appears. Thus, in all states of black display, halftone display, and white display, excellent display with little dependency on a viewing angle can be attained.

Now, FIGS. **10**A and **10**B are diagrams for explaining determination of an orientation by protrusions of dielectric material provided on the electrodes. In the specification, the dielectric materials are insulating materials of low dielectric. Referring to FIGS. **10**A and **10**B, an orientation determined by the protrusions will be discussed.

Protrusions are formed alternately on the electrodes **12** and **13**, and coated with the vertical alignment films **22**. A liquid crystal employed is of a negative type. As shown in FIG. **10**A, when no voltage is applied, the vertical alignment films **22** cause the liquid crystalline molecules to align vertically to the surfaces of the substrates. In this case, rubbing need not be performed on the vertical alignment films. Liquid crystalline molecules near the protrusions **20** try to align vertically to the inclined surfaces of the protrusions. The liquid crystalline molecules near the protrusions are therefore tilted. However, when no voltage is applied, in almost all regions of the liquid crystal other than the protrusions, liquid crystalline molecules are aligned nearly

vertically to the surfaces of the substrates. Consequently, as shown in FIG. **9**A, excellent black display can appear.

When a voltage is applied, the distribution of electric potentials in the liquid-crystal layer is as shown in FIG. **10**B. In the regions of the liquid-crystal layer without the protrusions, the distribution is parallel to the substrates (electric fields are vertical to the substrates). However, the distribution is inclined near the protrusions. When a voltage is applied, as shown in FIGS. **7**B and **7**D, the liquid crystalline molecules tilt according to an electric field strength. Since the electric fields are vertical to the substrates, when a direction of tilt is not defined by carrying out rubbing, the azimuth in which the liquid crystalline molecules tilt due to the electric fields includes all directions of 360°. If there are pre-tilted liquid crystalline molecules as shown in FIG. **10**A, surrounding liquid crystalline molecules are tilted in the directions of the pre-tilted liquid crystalline molecules. Even when rubbing is not carried out, the directions in which the liquid crystalline molecules lying in gaps between the protrusions can be restricted to the azimuths of the liquid crystalline molecules in contact with the surfaces of the protrusions. As shown in FIG. **10**B, the electric fields near the protrusions are inclined in directions in which they become parallel to the inclined surfaces of the protrusions. When a voltage is applied, the negative liquid crystalline molecules are tilted in directions vertical to the electric fields. The directions correspond to the directions in which the liquid crystalline molecules are pre-tilted because of the protrusions. Thus, the liquid crystalline molecules are aligned on a stabler basis. The slope of the protrusions and the electric fields in the proximity of the inclined surfaces of the protrusions contribute to stable alignment. Furthermore, when a higher voltage is applied, the liquid crystalline molecules become nearly parallel to the substrates.

As mentioned above, the protrusions fill the role of a trigger for determining azimuths in which the liquid crystalline molecules are aligned with application of a voltage. The protrusions need not have inclined surfaces (slopes) of large area. For example, the inclined surfaces over the whole pixel are unnecessary. However, if the size of the inclined surfaces is too small, the effect of the slope and electric field are not available. Therefore, the width of the inclined surfaces are required to be determined according to the materials and shape of the protrusions. Because a good result is obtained when the width of the protrusions is 5 μm. This means that when the width of the protrusions is larger than 5 μm, a good result can be certainly obtained. With small inclined surfaces, when no voltage is applied, the liquid crystalline molecules in almost all the regions of the liquid-crystal layer except the protrusions are aligned vertically to the surfaces of the substrates. This results in nearly perfect black display. Thus, a contrast ratio can be improved.

When the sections of the protrusions are rectangular, the side surfaces are almost vertical to the substrates. These side surfaces also operate as the domain regulating means. Therefore, the surfaces vertical to the substrates are included in the inclined surfaces.

The tilting direction of the orientation of the liquid crystal is decided by domain regulating means. FIG. **11** shows the orientation direction when protrusions are used as the domain regulating means. FIG. **11**A shows a bank having two slopes and the liquid crystalline molecules are oriented in two directions different from each other at an angle of 180 degrees with the bank being the boundary. FIG. **11**B shows a pyramid and the liquid crystalline molecules are oriented in four directions different from one another at an angle of 90 degrees with the apex of the pyramid being the boundary. FIG. **11**C shows a hemisphere and the orientation of the liquid crystalline molecules assumes symmetry of rotation with the axis of the hemisphere perpendicular to the substrate being the center. In the case of FIG. **11**C, the display state becomes the same for all the viewing angles. However, it cannot be said that a larger number of domains or directions is better. When the relationship to the direction of polarization offered by a sheet polarizer is taken into account, if the oblique orientation of the liquid crystal becomes rotationally symmetrical, there arises a problem that light use efficiency deteriorates. This is because when domains in the liquid crystal are defined uninterruptedly and radially, liquid crystalline molecules lying along a transmission axis and absorption axis of the sheet polarizer work inefficiently, and liquid crystalline molecules lying in directions of 45° with respect to the axes work most efficiently. For improving the light use efficiency, the directions included in the oblique orientation of the liquid crystal are mainly four directions or less. When there are four directions, they should preferably be directions in which light components to be projected on the display surface of the liquid crystal display propagate with azimuths mutually different in increments of 90°. In this case, the ratio in number of liquid crystalline molecules aligned in directions in which light components to be projected on the display surface propagate with azimuth mutually different by 180° should preferably be nearly even. Out of two sets of liquid crystalline molecules aligned in the directions in which the light components to be projected on the display surface propagate with azimuths mutually different by 180°, the ratio in number of aligned liquid crystalline molecules of one set is nearly even, while the ratio in number of aligned liquid crystalline molecules of the other set is uneven. The set of aligned liquid crystalline molecules of which ratio in number is nearly even is a majority, and the set of aligned liquid crystalline molecules of which ratio in number is uneven may be negligible. In other words, a characteristic analogous to that exhibited when two domains are defined in 180° different directions can be realized.

In FIGS. **9**A to **9**C, for realizing the domain regulating means, the electrodes **12** on the upper substrate are slitted and associated with pixels, and the electrode **13** on the lower substrate is provided with the protrusions **20**. Any other means will also do. FIGS. **12**A to **12**C are diagrams showing examples of realizing the domain regulating means. FIG. **12**A shows an example of realizing it by devising the shapes of the electrodes, FIG. **12**B shows an example of devising the contours of the surfaces of the substrates, and FIG. **12**C shows an example of devising the shapes of the electrodes and the contours of the surfaces of the substrates. In any of the examples, the orientations shown in FIG. **8** can be attained. However, the structures of liquid crystals are a bit different from one another.

In FIG. **12**A, ITO electrodes **41** and **42** on both substrates or one of the substrates are slitted. The surfaces of the substrates are processed for vertical alignment, and a negative liquid crystal is sealed in. When no voltage is applied, liquid crystalline molecules are aligned vertically to the surfaces of the substrates. When a voltage is applied, electric fields are generated obliquely to the surfaces of the substrates near the slits (edges) of the electrodes. With the oblique electric fields, the directions in which liquid crystalline molecules are tilted are determined. The orientation of the liquid crystal is divided as illustrated into right and left directions. In this example, the oblique electric fields induced near the edges of the electrodes are used to align the

liquid crystalline molecules rightward and leftward. This technique shall therefore be referred to as an oblique electric field technique.

In FIG. **12**B, protrusions **20** are formed on both the substrates. Like the structure shown in FIG. **12**A, the surfaces of the substrates are processed for vertical alignment, and a negative liquid crystal is sealed in. When no voltage is applied, the liquid crystalline molecules are aligned vertically to the surfaces of the substrates in principles. On the inclined surfaces of the protrusions, however, the liquid crystalline molecules are aligned at a little tilt. When a voltage is applied, the liquid crystalline molecules are aligned in the directions of tilt. Moreover, when an insulating material with low dielectric constant is used to form the protrusions, the electric fields are interrupted (state close to the state attained by the oblique electric field technique, the same state as the state attained by the structure having the electrodes slitted). More stable orientation division can be achieved. This technique shall be referred to as a both-side protrusion technique.

FIG. **12**C shows an example of combining the techniques shown in FIGS. **12**A and **12**B. The description will be omitted.

Three examples of realizing the domain regulating means have been presented. Moreover, various modifications can be devised. For example, the portions of the electrodes formed as the slits in FIG. **12**A may be dented, and the dents may be provided with inclined surfaces. Instead of making the protrusions in FIG. **12**B using an insulating material, protrusions may be formed on the substrates, and ITO electrodes may be formed on the substrates and protrusions. Thus, the electrodes having the protrusions may be realized. Even this structure can regulate the orientation of the liquid crystal. Moreover, dents may be substituted for the protrusions. Furthermore, any of the described domain regulating means may be formed on one of the substrates. When domain regulating means are formed on both the substrates, any pair of domain regulating means can be employed. Moreover, although the protrusions or dents should preferably be designed to have inclined surfaces, the protrusions or dents having vertical surfaces can also exert an effect of a certain level.

When the protrusions are formed, during black display, parts of the liquid crystal lying in the gaps between the protrusions are seen black, but light leaks out through parts thereof near the protrusions. This kind of partial difference in display is microscopic and indiscernible by naked eyes. The whole display exhibits averaged display intensity. The density for black display deteriorates a bit, whereby contrast deteriorates. When the protrusions are made of a material not allowing passage of visible light, contrast can be further improved.

When a domain regulating means is formed on one substrate or both substrates, protrusions, dents, or slits can be formed like a unidirectional lattice with a predetermined pitch among them. In this case, when the protrusions, dents, or slits are a plurality of protrusions, dents, or slits bent at intervals of a predetermined cycle, orientation division can be achieved more stably. Moreover, when the protrusions, dents, or slits are located on both substrates, they should preferably be arranged to be offset by a half pitch.

In the constitution disclosed in Japanese Unexamined Patent Publication (Kokai) No. 6-301036, apertures (slits) are provided on only the counter (CF) substrate. Therefore, the size of domain areas cannot be too small. Contrarily, according to the present invention, the size of domain areas can be optionally determined because the domain regulating means are provided on both of the pixel electrode and counter electrode. Further, at least one of the domain regulating means has inclined surfaces, the response speed can be improved.

On one of two upper and lower substrates, protrusions or dents may be formed like a two-dimensional lattice. On the other substrate, protrusions or dents may be arranged to be opposed to the centers of squares of the two-dimensional lattice.

In any case, it is required that orientation division occurs within each pixel. The pitch of the protrusions, dents, or slits must be smaller than that of pixels.

The results of examining the characteristics of an LCD in which the present invention is implemented demonstrate that a viewing angle characteristic is quite excellent and equal to or greater than those of not only a TN LCD but also an IPS LCD. Even when the LCD is viewed from its front side, the viewing angle characteristic is quite excellent, and the contrast ratio is 400 or more (twice as high as that offered by the TN LCD). The transmittance offered by the TN LCD is 30%, the one offered by the IPS LCD is 20%, and the one offered by the present invention is 25%. The transmittance offered by the present invention is lower than the one offered by the TN LCD but higher than the one offered by the IPS LCD. A response speed is outstandingly higher than those offered by the other modes. For example, as far as equivalent panels are concerned, a TN LCD panel exhibits an on speed (for transition from 0 V to 5 V) of 23 ms, an off speed (for transition from 5 V to 0 V) of 21 ms, and a response speed (on+off) of 44 ms, while an IPS LCD panel exhibits an on speed of 42 ms, an off speed of 22 ms, and a response speed of 64 ms. According to the mode of the present invention, the on speed is 9 ms, the off speed is 6 ms, and the response speed is 15 ms. Thus, the response speed is 2.8 times higher than the one offered by the TN mode and 4 times higher than the one offered by the IPS mode, and is a speed causing no problem in display of a motion picture.

Furthermore, in the mode of the present invention, when no voltage is applied, vertical alignment is achieved. When a voltage is applied, protrusions, dents, or oblique electric fields determine directions in which liquid crystalline molecules tilt. Unlike the ordinary TN or IPS mode, rubbing need not be carried out. In the process of manufacturing a panel, a rubbing step is a step likely to produce the largest amount of refuse. After the completion of rubbing, substrates must be cleaned (with running water or IPA) without fail. The cleaning may damage an alignment film, causing imperfect alignment. By contrast, according to the present invention, since the rubbing step is unnecessary, the step of cleaning substrates is unnecessary.

FIG. **13** is a diagram showing the overall configuration of a liquid crystal panel of the first embodiment of the present invention. As shown in FIG. **13**, the liquid crystal panel of the first embodiment is a TFT LCD. A common electrode **12** is formed on one glass substrate **16**. The other glass substrate **17** is provided with a plurality of scan bus lines **31** formed parallel to one another, a plurality of data bus lines **32** formed parallel to one another vertically to the scan bus lines, and TFTs **33** and cell electrodes **13** formed like a matrix at intersections between the scan bus lines and data bus lines. The surfaces of the substrates are processed for vertical alignment. A negative liquid crystal is sealed in between the two substrates. The glass substrate **16** is referred to as a color filter (CF) substrate because color filters are formed, while the glass substrate **17** is referred to as a TFT substrate. The details of the TFT LCD will be omitted. Now,

the shapes of the electrodes which are constituent features of the present invention will be described.

FIGS. **14**A and **14**B are diagrams showing the structure of a panel in accordance with the first embodiment of the present invention. FIG. **14**A is a diagram illustratively showing a state in which the panel is seen obliquely, and FIG. **14**B is a side view of the panel. FIG. **15** is a diagram showing the relationship between a pattern of protrusions and pixels in the first embodiment, FIG. **16** is a diagram showing the pattern of protrusions outside a display area of a liquid crystal panel of the first embodiment, and FIG. **17** is a sectional view of the liquid crystal panel of the first embodiment.

As shown in FIG. **17**, a black matrix layer **34**, an ITO film **12** providing color filters and a common electrode, and protrusions **20** parallel to one another with an equal pitch among them are formed on the surface of a side of a CF substrate **16** facing a liquid crystal. The ITO film and protrusions are coated with a vertical alignment film that is omitted therein. Gate electrodes **31** forming gate bus lines, CS electrodes **35**, insulating films **40** and **43**, electrodes forming data bus lines, an ITO film **13** providing pixel electrodes, and protrusions parallel to one another with an equal pitch among them are formed on the surface of a side of a TFT substrate **17** facing the liquid crystal. The TFT substrate is further coated with a vertical alignment film, though the vertical alignment film is omitted from the figure. Reference numerals **41** and **42** denote a source and drain of a TFT. In this embodiment, protrusions **20**A and **20**B are made of a TFT flattening material (positive resist).

As shown in FIG. **14**A, the pattern of the protrusions **20**A and **20**B is a pattern of parallel protrusions extending straightly and arranged with an equal pitch among them. The protrusions **20**A and **20**B are arranged to be offset by a half pitch. The structure shown in FIG. **14**B is thus realized. As mentioned in conjunction with FIG. **9**B, the orientation of the liquid crystal is divided into two directions to thus divide each domain into two regions.

The relationship of the pattern of protrusions to pixels is shown in FIG. **15**. As shown in FIG. **15**, in a general color-display liquid crystal display, three pixels of red, green, and blue constitute one color pixel. The width of each of the red, green, and blue pixels is approximately one-third of the length thereof so that color pixels can be arrayed with the same gap kept above and below them. A pixel defines each pixel electrode. Among arrayed pixel electrodes, gate bus lines (hidden behind the protrusions **20**B) are laid down sideways, and data bus lines **32** are laid down lengthwise. The TFTs **33** are located near intersections between the gate bus lines **31** and data bus lines **32**, whereby the pixel electrodes are interconnected. Opposed to the gate bus lines **31**, data bus lines **32**, and TFTs **33** included in the respective pixel electrodes **13** are black matrices **34** for intercepting light. Reference numeral **35** denotes CS electrodes used to provide a storage capacitor for stabilizing display are placed. Since the CS electrodes are light-interceptive, the CS-electrode portions of the pixel electrodes **13** do not work as pixels. Consequently, each pixel is divided into an upper part **13**A and lower part **13**B.

In each of the pixels **13**A and **13**B, three protrusions **20**A are lying and four protrusions **20**B are lying. Three first regions each having the protrusions **20**B on the upper side of the panel and the protrusions **20**A on the lower side thereof, and three second regions each having the protrusions **20**A on the upper side thereof and the protrusions **20**B on the lower side thereof are defined in one pixel composed of the pixels **13**A and **13**B. In the pixel composed of the pixels **13**A and **13**B, a total of six regions of the first and second regions are defined.

As shown in FIG. **16**, on the margin of the liquid crystal panel, the pattern of the protrusions **20**A and **20**B is extending outside topmost pixels and beyond rightmost pixels. This is intended to allow orientation division to occur in the outermost pixels in the same manner as that in the inner pixels.

FIGS. **18**A and **18**B are diagrams showing the position of a liquid-crystal injection port of the liquid crystal panel **100** of the first embodiment through which a liquid crystal is injected. As described later, in the process of assembling components to produce a liquid-crystal panel, after the CF substrate and TFT substrate are bonded to each other, a liquid crystal is injected. As far as a VA type TFT LCD is concerned, it takes much time to inject a liquid crystal compared with the TN LCD in general. Since protrusions are formed, it takes much more time to inject a liquid crystal. For shortening the time required for injecting the liquid crystal, as shown in FIG. **18**A, a liquid-crystal injection port **102** should preferably be formed on a side vertical to the direction in which the protrusions are arrayed parallel to one another on a cyclic basis. Reference numeral **101** denotes a sealing line.

During injection of a liquid crystal, when the interior of the panel is deaerated through exhaust ports **103** formed at another positions, the internal pressure decreases. This makes it easy to inject a liquid crystal. The exhaust ports should, as shown in FIG. **18**B, be located on a side opposite to the side on which the injection port is located.

FIG. **19** shows contours of protrusions in a prototype defined by performing measurement using a tracer type coating thickness meter. As illustrated, the gap between the ITO electrodes **12** and **13** formed on the substrates is restricted to 3.5 micrometers by means of spacers **45**. The protrusions **20**A and **20**B have a height of 1.5 micrometers and a width of 5 micrometers. A pair of upper and lower protrusions **20**A and **20**B are spaced by 15 micrometers. This means that a spacing between adjoining protrusions formed on the same ITO electrodes is 35 micrometers.

After an intermediate voltage is applied to the panel of the second embodiment, the interior of the panel is observed using a microscope. The observation has revealed that very stable alignment is attained.

Furthermore, in the panel of the first embodiment, a response speed has quite improved. FIGS. **20**A to **21** are diagrams indicating a changing value of the response speed permitted by the panel of the first embodiment in relation to changes in parameters that are an applied voltage and a spacing (gap) between upper and lower protrusions. FIG. **20**A indicates an on speed (for transition from 0 to 5 V), FIG. **20**B indicates an off speed (for transition from 5 to 0 V), and FIG. **21** indicates a switching speed that is a sum of the on speed and off speed. As shown in FIGS. **20**A to **21**, a fall time off is hardly dependent on the spacing but a rise time on varies greatly. The smaller the spacing is, the higher the response speed becomes. Incidentally, the thickness of cells is 3.5 micrometers. The practical value of the spacing varies slightly depending the thickness of cells. That is to say, when the thickness of cells is small, the spacing is widened. When the thickness of cells gets larger, the spacing is narrowed. It has been actually confirmed that as far as the spacing is about 100 times larger than the thickness of cells, liquid crystalline molecules are aligned properly.

In any case, the panel of the first embodiment permits the satisfactory switching speed. For example, when the spacing

between protrusions is 15 micrometers and the thickness of cells is 3.5 micrometers, the response speed for transition between 0 and 5 V, that is, the on time on is 9 ms, the off time off is 6-ms, and the switching speed 15 ms. Thus, very fast switching can be achieved.

FIGS. **22** to **24**B are diagrams showing the viewing angle characteristic of the panel of the first embodiment. FIG. **22** two-dimensionally shows a change in contrast dependent on a viewing angle, and FIGS. **23**A to **24**B show changes in display luminance levels corresponding to 8 gray-scale levels in relation to viewing angles. FIG. **23**A shows a change occurring at an azimuth of 90°, FIG. **23**B shows a change occurring at an azimuth of 45°, and FIG. **23**C shows a change occurring at an azimuth of 0°. FIG. **24**A shows a change occurring at an azimuth of −45°, and FIG. **24**B shows a change occurring at an azimuth of −90°. Hatched parts of FIG. **22** indicate areas in which a contrast is 10 or less, and double-hatched parts thereof indicate areas in which the contrast is 5 or less. As illustrated, a generally good characteristic is exhibited. However, since each pixel is divided vertically into two region, the characteristic is not a perfectly laterally and vertically uniform characteristic unlike the one provided by the first embodiment. Deterioration of contrast in a vertical direction is little larger than that in a lateral direction. The deterioration of contrast in the lateral direction is smaller than that in the vertical direction. However, as shown in FIG. **23**C, gray-scale reversal of black occurs at a viewing angle of about 30°. Sheet polarizers are bonded in such a way that the absorption axes thereof will lie at 45° and 135° respectively with respect to an optical axis. The viewing angle characteristic to be exhibited when the panel is viewed in an oblique direction is very good. The characteristics offered by this embodiment are overwhelmingly superior to those offered by the TN mode. However, this embodiment is slightly inferior to the IPS mode in terms of viewing angle characteristic. However, once one phase-difference film or optical compensation film is placed on the panel of the first embodiment, the viewing angle characteristic of the panel can be improved so greatly that it overwhelms the one offered by the IPS mode. FIGS. **25** to **26**C are diagrams showing a viewing angle characteristic to be exhibited by the panel of the first embodiment having the phase-difference film, and correspond to FIGS. **22** to **23**C. As illustrated, deterioration of contrast depending on a viewing angle has been drastically overcome. Moreover, gray-scale reversal occurring in a lateral direction on the panel has been overcome. On the contrary, gray-scale reversal occurs in a vertical direction during white display. However, generally, gray-scale reversal in white display is hardly visible to human eyes and is therefore not counted as a problem in terms of display quality. Thus, once the phase-difference film is employed, better characteristics than those offered by the IPS mode can be exhibited in all aspects including a viewing angle characteristic, response speed, and manufacturing difficulty.

An attempt was made to discuss optimal conditions by creating various variations of the structure of the first embodiment or modifying parameters other than the foregoing ones. In the case of protrusions, when the panel is displayed in black, light leaks out near the protrusions. FIG. **27** is a diagram for explaining occurrence of light leakage near the protrusions. As illustrated, light incident vertically on portions of the electrodes **13** on the lower substrate on which the protrusions **20** are formed is transmitted to some extent because liquid crystalline molecules are as illustrated aligned obliquely along the inclined surfaces of the protrusions **20**. This results in halftone display. By contrast, liquid crystalline molecules near the apices of the protrusions are aligned in a vertical direction. No light therefore leaks out near the apices. The same applies to the electrode **12** on the upper substrate. During black display, near the protrusions, halftone display and black display are carried out partially. This partial difference in display is microscopic and discernible to naked eyes. The whole display exhibits averaged display intensity. The black display deteriorates a bit, whereby contrast deteriorates. The protrusions are therefore made of a material not allowing passage of visible light, namely, made of material shielding visible light, whereby contrast improves. Even in the second embodiment, when the protrusions are made of a material shielding visible light, contrast can be further improved.

A change in response speed occurring when the spacing between protrusions is varied has been described in conjunction with FIGS. **20**A to **21**. A change in characteristic deriving from a change in height of protrusions was measured. The width of a photo-resist to be applied for realizing protrusions and the spacing between protrusions were 7.5 micrometers and 15 micrometers respectively, and the thickness of cells was approximately 3.5 micrometers. The height of the resist was set to 1.537 μm, 1.600 μm, 2.3099 μm, and 2.4486 μm. The transmittance and contrast ratio of a prototype were measured. The results of the measurement are shown in FIGS. **28** and **29**. A change in transmittance dependent on the height of the protrusions (resist) occurring in a white state (when 5 V is applied) is shown in FIG. **30**. A change in transmittance dependent on the height of the protrusions (resist) occurring in a black state (when no voltage is applied) is shown in FIG. **31**. A change in contrast ratio dependent on the height of the protrusions (resist) is shown in FIG. **32**. The higher the resist is, the higher the transmittance in the white state (when a voltage is applied) becomes. This is presumably attributable to the fact that the protrusions (resist) filling a supplementary role for tilting liquid crystalline molecules are large enough to turn down the liquid crystalline molecules in terms of both of figures and electrical effects. The transmittance (light leakage) in the black state (when no voltage is applied) increases with an increase in height of the resist. This causes black levels to fall and is therefore not very preferable. The causes of light leakage will be described in conjunction with FIG. **27**. Liquid crystalline molecules lying immediately above the protrusions (resist) and in the spacings between the protrusions are aligned vertically to the surfaces of the substrates. Light leakage does not occur in these places. However, liquid crystalline molecules lying on the slopes of the protrusions are aligned slightly obliquely. As the protrusions get higher, the area of the slopes increases and a light leakage increases.

The contrast (white luminance level/black luminance level) decreases as the resist gets higher. However, even when the height of the resist is increased to have the same value as the thickness of cells, screen display can be achieved without any problem. In this case, as described later, the protrusions (resist) can be designed to fill the role of panel spacers.

Based on the above results, prototypes of liquid crystal displays of size 15 were produced using TFT substrates and CF substrates having protrusions of 0.7 micrometers, 1.1 micrometers, 1.5 micrometers, and 2.0 micrometers in height. The trend revealed by the results of the experiment was also observed in the actually-produced liquid crystal panels. For actual viewing, because the contrast has been originally high, deteriorations in contrast occurring in the panels produced under the different conditions were of a

good level. Thus, satisfactory display was achieved. This is presumably because the panels originally permitted high contrasts and a little decrease in contrast was indiscernible to human eyes. Moreover, a panel including protrusions of 0.7 micrometers high was also produced in an effort to detect the lower limit of the height of the protrusions working on molecular alignment. Display was perfectly normal. Consequently, even when the height of the protrusions (resist) is as small as 0.7 micrometers or less, the protrusions can satisfactorily work on alignment of liquid crystalline molecules.

FIG. **33** is a diagram showing a pattern of protrusions in the second embodiment. As shown in FIG. **15**, in the first embodiment, protrusions are linear and extending in a direction vertical to the longer sides of pixels. In the second embodiment, protrusions are extending in a direction vertical to the shorter sides of pixels **9**. The other components of the second embodiment are identical to those of the first embodiment.

FIGS. **252**A and **252**B show a modification of the second embodiment, wherein FIG. **252**A shows a protrusion pattern and FIG. **252**B is a sectional view showing the arrangement of the protrusion arrangement. In this modification, the protrusion **20**A disposed on the electrode **12** on the side of the CF substrate **16** is extended in such a fashion as to pass through the center of the pixel **9** and to extend in a direction perpendicular to the minor side of the pixel **9**. No protrusion is disposed on the side of the TFT substrate **17**. Therefore, the liquid crystal is oriented in two directions inside each pixel. As shown in FIG. **252**B, the domain is divided by the protrusion **20**A at the center of the pixel. Since the edge of the pixel electrode serves as the domain regulating means around the pixel electrode **13**, the orientation can be divided stably. In this modification, only one protrusion is disposed for each pixel and the distance between the protrusion **20**A and the edge of the pixel electrode **13** is great. Therefore, the response speed becomes lower than in the second embodiment but the production process becomes simpler because the protrusion is disposed on only one of the sides of the substrate. Further, because the occupying area of the protrusion inside the pixel is small, display luminance can be improved.

FIG. **253** shows a protrusion pattern of another modification of the second embodiment. The protrusion **20**A disposed on the electrode **12** on the side of the CF substrate **16** is positioned at the center of the pixel **9**, and no protrusion is disposed on the side of the TFT substrate **17**. The protrusion **20**A is a pyramid, for example. Therefore, the liquid crystal is oriented in four directions inside each pixel. This modification can obtain the same effect as that of the modification shown in FIG. **255** and because the occupying area of the protrusion inside the pixel is further smaller, display luminance can be all the more improved.

In the first and second embodiments, numerous linear protrusions extending unidirectionally are located parallel to one another. Orientation division caused by the protrusions divides each domain mainly into two regions. Azimuths with which liquid crystalline molecules in two regions are aligned differ from each other by 180°. The viewing angle characteristic for a halftone exhibited relative to light components propagating inside a panel with azimuths including an azimuth corresponding to a direction in which liquid crystalline molecules are aligned vertically to the substrates will be improved as shown in FIGS. **9**A to **9**C. As for the viewing angle characteristic exhibited relative to light components propagating vertically to the light components, the problem described in conjunction with FIGS. **7**A to **7**C occurs. For this reason, orientation division should preferably be division of the orientation into four directions.

FIG. **34** is a diagram showing a pattern of protrusions in the third embodiment. As shown in FIG. **34**, in the third embodiment, a pattern of protrusions extending lengthwise and a pattern of protrusions extending sideways are created within each pixel **9**. Herein, the pattern of protrusions extending lengthwise is created in the upper half of one pixel, and the pattern of protrusions extending sideways is created in the lower half thereof. In this case, the pattern of protrusions extending lengthwise divides the orientation of the liquid crystal sideways into azimuths that are mutually different by 180°, that is, divides each pixel or domain sideways into two regions. The pattern of protrusions extending sideways divides the orientation of the liquid crystal lengthwise into azimuths that are mutually different by 180°, that is, divides each pixel or domain lengthwise into two regions. Consequently, the orientation of the liquid crystal within one pixel **9** is divided into four directions. Talking of the whole liquid crystal panel, the viewing angle characteristics thereof relative to both the vertical direction and lateral direction are improved. In the third embodiment, the components other than the pattern of protrusions are identical to those of the first embodiment.

FIG. **35** is a diagram showing a modification of the pattern of protrusions of the third embodiment. This modification is different from the third embodiment shown in FIG. **34** in a point that a pattern of protrusions extending lengthwise is created in the left half of each pixel, and a pattern of protrusions extending sideways is created in the right half thereof. Even in this case, like the patterns of protrusions shown in FIG. **34**, the orientation of the liquid crystal is divided into four directions within each pixel **9**. The viewing angle characteristics of the panel relative to both the vertical direction and lateral direction are improved.

The first to third embodiments use protrusions as a domain regulating means for realizing orientation division. As shown in FIG. **36**, the alignment of liquid crystalline molecules near the apices of the protrusions is not regulated at all. Near the apices of the protrusions, the alignment of liquid crystalline molecules is therefore not controlled to deteriorate display quality. The fourth embodiment is an example for solving this kind of problem.

FIGS. **37**A and **37**B are diagrams showing the shapes of protrusions in the fourth embodiment. The other components are identical to those of the first to third embodiments. In the fourth embodiment, as shown in FIG. **37**A, the protrusions **20** are partly tapered. The length of the taper portions is about 50 micrometers or less than it. For creating a pattern of this kind of protrusions, the pattern is drawn using a positive resist, and the protrusions and taper portions are created by performing slight etching. With the thus created protrusions, the alignment of liquid crystalline molecules near the apices of the protrusions can be controlled.

Moreover, in a modification of the fourth embodiment, as shown in FIG. **37**B, tapered juts **46** are formed on each protrusion **20**. Even in this case, the length of each tapered portion is about 50 micrometers or less than it. For creating a pattern of this kind of protrusions, the pattern is drawn using a positive resist, and the protrusions **20** are created by performing slight etching. A positive resist whose thickness is about a half of the height of the protrusions is applied, and the tapered juts **46** on the protrusions **2** are left intact by performing slight etching. With the juts, the alignment of liquid crystalline molecules near the apices of the juts can be controlled.

FIGS. **38**A and **38**B are diagrams showing the structure of a panel in the fifth embodiment. FIG. **38**A is a diagram illustratively showing a state in which the panel is seen obliquely, and FIG. **38**B is a side view. The fifth embodiment is an example in which the structure of a panel corresponds to the structure shown in FIG. **12**C. The protrusions **20**A are created as illustrated on the electrode **12** (herein, a common electrode) formed on the surface of one substrate by applying a positive resist, and the slits **21** are created in the electrodes **13** (herein, cell (pixel) electrodes) formed on the surface of the other substrate.

Cost serves as an important factor for determining whether a liquid crystal display device could become commercially successful or not. The liquid crystal display device of the VA system and, particularly, the VA system equipped with a domain regulating means features a high display quality as described above but becomes expensive due to the provision of the domain regulating means and, hence, it has been desired to further decrease the cost.

When the protrusion is formed on the electrode, the photoresist that is applied must be exposed to light through a pattern followed by developing and etching, requiring an increased number of steps and increased cost, deteriorating the yield. On the other hand, the pixel: electrode must be formed by patterning, and the number of the steps does not increase despite a pixel electrode having a slit is formed. On the side of the TFT substrate, therefore, the cost can be decreased when the domain regulating means is formed by slits rather than protrusions. On the other hand, the opposing electrode of the color filter substrate (CF substrate) is usually a flat electrode. When a slit is to be formed in the opposing electrode, an etching step must be executed after the patterned photoresist is developed. When the protrusion is to be formed on the opposing electrode, however, the developed photoresist can be used in its form without much driving up the cost of forming the protrusion. Like in the liquid crystal display device of the first embodiment of the present invention, therefore, the domain regulating means on the side of the TFT substrate is formed by a slit in the pixel electrode and the domain regulating means on the side of the color filter substrate is formed by a protrusion, driving up the cost little.

FIG. **39** is a diagram showing a pattern of slits of each pixel electrode in a modification of the fifth embodiment. This modification corresponds to an example in which the protrusions **20**B are replaced with the slits **21** in the third embodiment.

When a slit is formed in the pixel electrode to divide it into a plurality of partial electrodes, the same signal voltage must be applied to these partial electrodes, and electric connection portions must be provided to connect the partial electrodes together. When the electric connection portions are formed on the same layer as the pixel electrodes, orientation of liquid crystals is disturbed in the electric connection portions impairing viewing angle characteristics, luminance of the panel and response speed.

According to this as shown in FIG. **39**, therefore, the electric connection portions are formed in the perimeter of the pixel electrode **13** and are shielded by the black matrices (BM) **34** to obtain luminance and response speed comparable with those of when protrusions are formed on both of them. In this embodiment in which the CS electrode **35** having light-shielding property is provided at the central portion of the pixel, the pixel is divided into upper and lower two portions. Reference numeral **34**A denotes an opening of the upper side defined by BM, and **34**B denotes an opening of the lower side defined by BM, and light passes through the inside of the openings.

The bus lines such as gate bus lines **31** and data bus lines **32** are made of a metal material and have light-shielding property. To obtain stable display, the pixel electrodes must be so formed as will not be superposed on the bus lines, and light must be shielded between the pixel electrodes and the bus lines. Furthermore, when amorphous silicon is used as operation semiconductor, the element characteristics undergo a change upon the incidence of light giving rise to the occurrence of erroneous operation. Therefore, the TFT portions must be shielded from light. Therefore, the BM **34** has heretofore been provided for shielding light for these portions. According to this embodiment, the electric connection portions are provided in the perimeter of the pixel, and light is shielded by the BM **34**. There is no need to newly provide the BM for shielding light for the electric connection portions; i.e., the conventional BM may be used or the BM may be slightly expanded without decreasing the numerical aperture to a serious degree.

The panel of the fifth embodiment is of a type in which each pixel is divided into two portions, and therefore basically exhibits the same characteristics as the one of the first embodiment. The viewing angle characteristic of the panel becomes identical to that of the panel of the second embodiment when the phase-difference film or optical compensation film is employed. The response speed of the panel is slightly lower than that of the panel of the first embodiment, because oblique electric fields induced by the slits formed in one substrates are utilized. Nevertheless, the on speed is 8 ms, the off speed is 9 ms, and the switching speed is 17 ms. Thus, the response speed is much higher than the ones offered by the conventional modes. As mentioned above, display is seen little irregular. However, the manufacturing process is simpler than those of the first and second embodiments. For example, in the course of forming ITO pixel electrodes (cell electrodes) on a TFT substrate, the electrodes are slitted. A pattern of protrusions is then drawn on a common electrode using a photo-resist. As already described, the rubbing step is unnecessary, and the associated after-rubbing cleaning step can therefore be omitted.

For the reference, the measurement results of an example in which slits are provided on the cell (pixel) electrode and no slit is provided on the counter electrode is described. In this example, the cell electrodes have the slits, and the width and pitch of the slits are determined properly. Owing to this constitution, stable alignment is attained, that is, liquid crystalline molecules are aligned in all azimuths of 360° inside walls defined with oblique electric fields induced near the slits. The liquid crystalline molecules are aligned in all azimuths of 360° within each small region. The viewing angle characteristic of the panel is therefore excellent. An image that is seen homogeneous in all azimuths of 360° can be produced. However, a response speed has not been improved. An on speed is 42 ms, and an off speed is 15 ms. A switching speed that is a sum of the on and off speeds is 57 ms. Thus, the response speed has not been improved very much. This means that no problem occurs in displaying a still image but the response speed is not high enough to display a motion picture like the one offered by the IPS mode. If a number of the slits is decreased, the response speed is further decreased. This is presumably that when the number of the slits is decreased, the area of each domain becomes large, and it lengthens a time in which all liquid crystalline molecules are oriented.

In the fifth embodiment, when a voltage is applied, the liquid crystal has portions, in which molecular alignment is unstable. The reason will be described with reference to FIGS. **40** and **41**. FIG. **40** is a diagram illustrating the distribution of orientation of liquid crystalline molecules in the electric connection portions. In a portion where the protrusion **20**A and the slit **21** are provided in parallel, the liquid crystalline molecules are oriented in a direction perpendicular to the direction in which the protrusion and the slit extend as viewed from the upper side. In the electric connection portion, however, the liquid crystalline molecules **14***a* are oriented in different directions, developing abnormal orientation. Therefore, as shown in FIG. **41**, liquid crystalline molecules in the spaces between the protrusions **20**A and the slits **21** of the electrodes are aligned in a direction vertical (vertical direction in the drawing) to the protrusions **20**A and slits **21**. Near the apices of the protrusions and the centers of the slits, liquid crystalline molecules are aligned in a horizontal direction but not in the vertical direction. Oblique electric fields induced by the slopes of the protrusions or the slits enable control of the liquid crystal in the vertical direction in the drawing but cannot enable control in the lateral direction. For this reason, a random domain is produced sideways near the apices of the protrusions and the centers of the slits. This has been confirmed through microscopic observation. A domain near the apex of a protrusion is too small to be discerned, causing no problem. However, an area occupied by a domain having liquid crystalline molecules aligned sideways and lying near a slit is so large as to be discerned even by naked eyes. When the domain is produced regularly, even if the domain is large, it will not be cared. However, when the domain is produced at random, an image is seen irregular. This leads to deteriorated display quality. The panel in the fifth embodiment makes a little poor impression on image quality compared with the one provided by the first embodiment, though display has no problem.

Abnormal orientation causes the luminance of the panel and the response speed to decrease. For example, a comparison of a practical device in which an electric connection portion is formed at the central portion of the pixel electrode with a practical device in which a protrusion is provided, indicates abnormal conditions such as a drop in the luminance and a residual image in which white appears bright for a moment when black changes into white. In the sixth embodiment, this problem is solved.

A panel of the sixth embodiment is provided by modifying the shape of the protrusions **20**A and that of the slits **21** in the cell electrodes **13** in the panel of the fifth embodiment. FIG. **42** is a diagram showing the shape of the protrusions **20**A of the sixth embodiment and that of the cell electrodes **13** thereof which are seen in a direction vertical to the panel. As illustrated, the protrusions **20**A are zigzagged. Owing to this shape, as shown in FIG. **43**, a domain divided regularly into four regions is produced. Consequently, irregular display that poses a problem in the fifth embodiment can be overcome.

FIG. **44** is a plan view of a pixel portion in the LCD according to a sixth embodiment of the present invention, FIG. **45** is a diagram illustrating a pattern of a pixel electrode according to the sixth embodiment, and FIG. **46** is a sectional view of a portion indicated by A-B in FIG. **44**.

Referring to FIGS. **44** and **46**, in the LCD of the sixth embodiment, on one glass substrate **16** are formed a black matrix (BM) **34** for shielding light and a color decomposition filter (color filter) **39**, and a common electrode **12** is formed on one surface thereof. Moreover, sequences of protrusions **20**A are formed in a zig-zag manner. The glass substrate **16** on which the color filter **39** is formed is called color filter substrate (CF substrate). On the other glass substrate **17** are formed a plurality of scan bus lines **31** arranged in parallel, a plurality of data bus lines **32** arranged in parallel in a direction perpendicular to the scan bus lines, TFTs **33** arranged like a matrix to correspond to the intersecting points of the scan bus lines and the data bus lines, and display pixel (cell) electrodes **13**. The scan bus lines **31** form gate electrodes of the TFTs **33**, and the data bus lines **32** form drain electrodes **42** of the TFTs **33**. The sources **41** are formed in the same layers as the data bus lines **32** and are formed simultaneously with the formation of the drain electrodes. A gate-insulating film, an amorphous silicon active layer and a channel protection film are formed on predetermined portions between the scan bus line **31** and the data bus line **32**, an insulating film is formed on the layer of the data bus line **32** and, besides, an ITO film corresponding to the pixel electrode **13** is formed thereon. The pixel electrode **13** is of a rectangular shape of 1:3 as shown in FIG. **45**, and has a plurality of slits **21** in a direction tilted by 45 degrees with respect to the sides thereof. In order to stabilize the potential of every pixel electrode **13**, furthermore, a CS electrode **35** is provided to form a storage capacitor. The glass substrate **17** is called TFT substrate.

As shown, the sequences of protrusions **20**A of the CF substrate and the slits **21** of the TFT substrates are arranged being deviated by one-half pitch of their arrangement, so that the substrates maintain an inverse relationship. The protrusions and the slits maintain a positional relationship as shown in FIG. **12**C, and the orientation of the liquid crystals is divided into four directions. As described above, the pixel electrode **13** is formed by forming an ITO film, applying a photoresist thereon, exposing it to light through a pattern of electrode, followed by developing and etching.

Therefore, the slit can be formed through the same step as the conventional step if the patterning is so effected as to remove the portion of the slit, without driving up the cost.

Upon forming the slits in the pixel electrode **13**, the pixel electrode **13** is divided into a plurality of partial electrodes. Here, however, a signal of the same voltage must be applied to the partial electrodes and, hence, the partial electrodes must be electrically connected together. According to this embodiment as shown in FIG. **45**, therefore, the pixel electrode **13** is not completely divided by slits, but the electrode is left at the perimetric portions **131**, **132**, **133** of the pixel electrode **13** to form electric connection portions. As described above, the alignments of the molecules are disturbed near the electric connection portions. Therefore, according to this embodiment as shown in FIG. **10**, the electric connection portions are formed in the perimeter of the pixel electrode **13** and are shielded by the BM **34** to obtain luminance and response speed comparable with those of when protrusions are formed on both of them. In this embodiment in which the CS electrode **35** having light-shielding property is provided at the central portion of the pixel, the pixel is divided into upper and lower two portions. Reference numeral **34**A denotes an opening of the upper side defined by BM, and **34**B denotes an opening of the lower side defined by BM, and light passes through the inside of the openings.

FIGS. **47** to **48**C are diagrams showing a viewing angle characteristic exhibited by the sixth embodiment. As illustrated, the viewing angle characteristic is excellent and irregular display is overcome. Moreover, a response speed is as high as a switching speed is 17.7 ms. Thus, very fast switching can be achieved.

FIGS. **49**A and **49**B illustrate another example of the pattern of the pixel electrode, wherein the BM **34** shown in FIG. **49**B is formed on the pixel electrode **13** shown in FIG. **49**A. The pattern of the pixel electrode can be modified in a variety of ways. For example, electric connection portions may be formed in the perimeter on both sides of the slit to decrease the resistance between the partial electrodes.

In the fifth and sixth embodiments, slits can be provided in the place of the protrusions on the counter electrode **12**. Namely, both of the domain regulating means are realized by the slits. However, in this constitution, the response speed is decreased.

In the sixth embodiment, the electric connection portions are formed in the same layer as the partial electrodes. The electric connection portions, however, may be formed in a separate layer. A seventh embodiment deals with this case.

FIGS. **50**A and **50**B are diagrams illustrating a pattern and a structure of the pixel electrode according to the seventh embodiment. The seventh embodiment is the same as the sixth embodiment except that the connection electrode **134** is formed simultaneously with the formation of the data bus line **32**, and a contact hole is formed in the insulating layer **135** to connect the partial electrode **13** to the connection electrode **134**. In this embodiment, the connection electrode **134** is formed simultaneously with the data bus line **32**. However, the connection electrode **134** may be formed simultaneously with the gate bus line **31** or the CS electrode **35**. The connection electrode may be formed separately from the formation of the bus line. In this case, however, a step must be newly provided for forming the connection electrode, i.e., a new step must be added. In order to simplify the steps, it is desired to form the connection electrode simultaneously with the formation of the bus line or the CS electrode.

In the seventh embodiment, the connection electrode which becomes a cause of abnormal orientation is more separated away from the liquid crystal layer than that of the sixth embodiment, making it possible to further decrease abnormal orientation. When the connection electrode is formed of a light-shielding material, such a portion is shielded from light, and the quality of display is further improved.

FIG. **51** is a plan view of a pixel portion according to a eighth embodiment, and FIG. **52** is a sectional view of a portion A-B in FIG. **51**. The eighth embodiment is the same as the sixth embodiment except that a protrusion **20**C is formed in the slit of the pixel electrode **13**. Both the slit of the electrode and the insulating protrusion formed on the electrode define the orientation region of the liquid crystals. When the protrusion **20**C is formed in the slit **21** as in this embodiment, the directions of orientation of the liquid crystals due to the slit **21** and the protrusion **20**C are in agreement, the protrusion **20**C assisting the division of orientation by the slit **21**, to improve stability. Therefore, the orientation is more stabilized and the response speed is more increased than those of the first embodiment. Referring to FIG. **52**, the protrusion **20**C is formed by laminating the layers that are formed when the CS electrode **35**, gate bus line **31** and data bus line **32** are formed.

FIGS. **53**A to **53**J are diagrams illustrating a process for producing a TFT substrate according to the eighth embodiment. In FIG. **53**A, a metal film of the gate layer is formed on a glass substrate **17**. In FIG. **53**B, portions corresponding to gate bus lines **31**, CS electrodes **35** and protrusions **312** are left relying upon the photolithography method. In FIG. **53**C, a gate-insulating film, an amorphous silicon active layer and a channel protection film are continuously formed.

In FIG. **53**D, the channel protection film **314** is left in a self-aligned manner by exposure to light through the back surface. In FIG. **53**E, a metal film **321** is formed for forming the contact layer and the source-drain layer. In FIG. **53**F, a source electrode **41** and a drain electrode **42** are formed relying on the photolithography method. At this moment, the metal film is left even at a position corresponding to the protrusion **20**C on the inside of the slit. In FIG. **53**G, a passivation film **33** is formed. In FIG. **53**H, a contact hole **332** is formed for the source electrode **41** and the pixel electrode. In FIG. **53**I, an ITO film **341** is formed. In FIG. **53**J, a pixel electrode **13** is formed by the photolithography method. Slits are formed at this moment.

According to this embodiment as described above, the protrusion **20**C is formed in the slit **21** of the pixel electrode **13** without, however, increasing the number of the steps compared with the conventional process. Besides, the orientation is further stabilized owing to the protrusion **20**C. In this embodiment, the protrusion in the slit of the pixel electrode is formed by superposing three layers, i.e., gate bus line layer, channel protection layer and source/drain layer. The protrusion, however, may be formed by one layer or by a combination of two layers.

FIG. **54** is a diagram showing the shape of the protrusions **20**A and **20**B in the ninth embodiment which are seen in a direction vertical to the panel. FIG. **55** is a diagram showing a practical plan view of pixel portions of the ninth embodiment. A panel of the ninth embodiment of the present invention is provided by zigzagging the protrusions **20**A and **20**B in the panel of the first embodiment like those in the one of the sixth embodiment. As illustrated, the protrusions **20**A and **20**B are zigzagged so that an: orientation causing each domain to be divided into four regions can be attained. The directions of the surfaces of each protrusion reaching and receding from a bent are mutually different by 90°. Since liquid crystalline molecules are aligned in a direction vertical to the surfaces of each protrusion, an orientation causing each domain to be divided into four regions can be attained. In practice, a panel in which a thickness of the liquid crystal layer is 4.1 μm, a width and height of the protrusions **20**A are respectively 10 μm and 4 μm, a width and height of the protrusions **20**B are respectively 5 μm and 1.2 μm, a gap between the protrusions **20**A and **20**B (a distance in the direction shifted by 45° from the horizontal line in the figure) is 27.5 μm, and a size of the pixel (pixel arrangement pitches) is 99 μm×297 μm has been made. As a result of measurement of this panel, the response speed of the panel is identical to that of the panel of the first embodiment. The viewing angle characteristic thereof is identical to the one in the sixth embodiment, and is so excellent as to demonstrate that the orientation is divided vertically and laterally uniformly. Optimal values of the width, height and gap of the protrusions have relations to each other. Further, they are changed according to materials of the protrusions, vertical alignment film, liquid crystal, a thickness of the liquid crystal layer and so forth.

In the panel in the ninth embodiment, the direction of tilt of liquid crystalline molecules can be controlled to include four directions. Regions A, B, C, and D in FIG. **54** are regions to be controlled so that liquid crystalline molecules therein will be aligned in the four directions. The ratio of the regions within one pixel is uneven. This is because the pattern of protrusions is continuous and is located in the same way in all pixels, and a pitch of repeated patterns of protrusions is matched with a pitch of arrayed pixels. In reality, the viewing angle characteristic shown in FIGS. **47** to **48**C is exhibited but does not reflect the uneven ratio of

regions resulting from orientation division. However, this state is not very preferable. The pattern of protrusions shown in FIG. **54** is therefore formed all over the substrates with the pitch of pixels ignored. The width of a resist is 7 micrometers, an interval between resist lines is 15 micrometers, the height of the resist is 1.1 micrometers, and the thickness of cells is 3.5 micrometers. Using a TFT substrate and CF substrate meeting these conditions, a liquid crystal display of size 15 was produced as a prototype. Some resist lines interfered with gate bus lines and data bus lines. Nevertheless, generally good display appeared. Even when the width of the resist was increased to be 15 micrometers and the interval between resist lines was increased to 30 micrometers, nearly the same results were obtained. Consequently, when the width of protrusions and the pitch of repeated patterns are made much smaller than the pitch of pixels, even if a pattern of protrusions is drawn with the dimensions of a pixel ignored, good display can be attained. Besides, the freedom in design expands. For completely preventing interference with bus lines, the pitch of repeated patterns of protrusions or dents should be set to an integral submultiple or multiple of the pitch of pixels. Likewise, a cycle of protrusions must be designed in consideration of a cycle of pixels and should preferably be set to an integral submultiple or multiple of the pitch of pixels.

In the ninth embodiment, when a pattern of protrusions that is discontinuous like the one shown in FIG. **56** is adopted, the ratio of regions within one pixel in which liquid crystalline molecules are aligned in four different directions is even. There is still no particular problem in manufacturing. However, since the pattern of protrusions is discontinuous, the orientation of the liquid crystal is disordered at the edges of patterns. This leads to deteriorated display quality such as light leakage. Even from this viewpoint, preferably, the pitch of repeated patterns of protrusions should be matched with the pitch of arrayed pixels, and a continuous pattern of protrusions should be adopted.

In the ninth embodiment, the protrusions of dielectric materials are formed in a zig-zag manner on the electrodes **12**, **13** as the domain regulating means and the protrusions regulate the alignment direction of the liquid crystalline molecules. As described above, the slits provided on the electrodes generate oblique electric fields, at the edges thereof, and the oblique electric fields operate as the domain regulating means. The edges of the cell (pixel) electrodes also generate oblique electric field. Therefore, the oblique electric field must be considered as the domain regulating means.

FIGS. **57**A and **57**B are diagrams for explaining this phenomenon and shows the case of the vertical orientation somewhat inclined from the vertical direction. As shown in FIG. **57**A, each liquid crystal particle **14** is oriented substantially vertically when no voltage is applied thereto. Upon application of a voltage between electrodes **12** and **13**, however, an electric field is generated in vertical direction in the electrodes **12** and **13** in the region other than the perimeter of the electrode **13**, so that the liquid crystalline molecules **14** are tilted in the direction perpendicular to the electric field. One electrode is a common electrode, and the other electrode is a display pixel electrode separated into each display pixel. Therefore, as shown in FIG. **57**B, the direction of the electric field **8** is inclined at its perimetric edge (edge). The liquid crystalline molecules **14** are tilted in the direction perpendicular to the electric field **8**. The direction of inclination of the liquid crystal, therefore, is different between the central portion and the edge of the pixel as shown. This phenomenon is called “reverse tilt”. A

reverse tilt causes a schlieren structure to be formed in the display pixel area and thus deteriorates the display quality.

The reverse tilt also occurs in the case where the domain regulating means is used. FIG. **58** is a diagram showing a portion **41** where the schlieren structure can be observed in a configuration formed with the zigzag protrusion pattern of the ninth embodiment. FIG. **59** is a diagram showing in enlarged form the neighborhood of the portion **41** where a schlieren structure is observed and also shows the direction in which the liquid crystalline molecules **14** are tilted upon application of a voltage thereto. In this case, protrusions of different materials are formed on the pixel electrode substrate formed with a TFT and on the opposed substrate formed with a common electrode . . . A vertical alignment film is printed, and the device is assembled without being rubbed. The cell thickness is 3.5 μm. The portion **41** where the schlieren structure is observed is where the direction in which the liquid crystalline molecules are fallen by the orientation regulation force due to the diagonal electric field is considerably different from the direction of orientation regulation due to the protrusions. This reduces the contrast and the response rate, thereby leading to a deteriorated display quality.

In the case where the liquid crystal display device configured of a protrusion pattern bent in zigzag in the ninth embodiment is driven, the display is darkened in a part of the display pixels, or a phenomenon called an after-image in which a somewhat previous display appears remaining occurs in the display of an animation or cursor relocation. FIG. **60** is a diagram showing a region appearing black in the pixel on the liquid crystal panel configured in the ninth embodiment. In this region, the change in orientation is found to be very slow upon application of a voltage.

FIG. **61**A is a sectional view taken in line A-A' in FIG. **60**, FIG. **61**B is a sectional view taken in line B-B'. As shown in FIG. **60**, the section A-A' has a region looking black in the neighborhood of the left edge, while the neighborhood of the right edge lacks a region appearing black. In correspondence with this, as shown in FIG. **61**A, the direction in which the liquid crystalline molecules are tilted by the orientation regulation force due to the diagonal electric field is considerably different from the direction of orientation regulation due to the protrusions in the neighborhood of the left edge, while the direction in which the liquid crystalline molecules are tilted by the orientation regulation force due to the diagonal electric field comparatively coincides with the direction of orientation regulation due to the protrusions in the neighborhood of the right edge. In similar fashion, a region looking black is present in the neighborhood of the right edge but absent in the neighborhood of the left edge. In correspondence with this, as shown in FIG. **61**B, the direction in which the liquid crystalline molecules are tilted by the orientation regulation force due to the diagonal electric field is considerably different from the direction of orientation regulation due to the protrusions in the neighborhood of the right edge, while the direction in which the liquid crystalline molecules are tilted by the orientation regulation force due to the diagonal electric field comparatively coincides with the direction of orientation regulation due to the protrusions in the neighborhood of the left edge.

As described above, the deterioration of the display quality is attributable to the portion where the direction in which the liquid crystalline molecules are tilted by the orientation regulation force due to the diagonal electric field at an edge of the display pixel electrode is considerably different from the orientation regulation force due to the protrusions upon application of a voltage thereto.

In the case where a liquid crystal display device having a configuration with a protrusion pattern is driven, the display quality is seen to deteriorate in the neighborhood of the bus line (gate bus line or data bus line) in the pixel. This is due to the undesirable minute region (domain) formed in the neighborhood of the bus line and the resulting disturbance of liquid crystal orientation and reduced response rate. The problem thus is posed of a reduced viewing angle characteristic and a reduced color characteristic in half tone.

FIGS. **62**A and **62**B are diagrams showing a fundamental configuration of a LCD according to a tenth embodiment. A pixel functions within the range defined by a cell electrode **13**, which will be called a display region and the remaining part a non-display region. Normally, a bus line and a TFT are arranged in a non-display region. A bus line made of a metal material has a masking characteristic but a TFT transmits light. As a result, a masking member called a black matrix (BM) is inserted between a TFT, a cell electrode and a bus line.

According to the tenth embodiment, a protrusion **20**A is arranged in the non-display region on a common electrode **12** of a CF substrate **16** so as to generate an orientation regulation force in a direction different from the orientation restriction force exerted due to a diagonal electric field generated by an edge of the cell electrode **13**. FIG. **62**A, shows the state where no voltage is applied. In this state, liquid crystalline molecules **14** are oriented substantially perpendicular to the surfaces of the electrodes **12**, **13** and the protrusion **20**A due to the vertical orientation process. Upon application of a voltage thereto, as shown in FIG. **62**B, the liquid crystalline molecules **14** are oriented in the direction perpendicular to the electric field **8**. In the non-display region lacking the cell electrode **13**, the electric field is formed diagonally from the neighborhood of an edge of the cell electrode **13** toward the non-display region. This diagonal electric field tends to orient the liquid crystalline molecules **14** in a direction different from the orientation in the display region as shown in FIG. **57**B. The orientation regulation force of the protrusion **42**, however, orients the liquid crystalline molecules **14** in the same direction as in the display region, as shown in FIG. **62**A.

FIG. **63** is a diagram showing a protrusion arrangement pattern in a liquid crystal display device of the tenth embodiment. FIG. **64** is a diagram showing, in enlarged form, the portion defined by a circle in FIG. **63**. In the tenth embodiment, a new protrusion **52** is formed in the vicinity of the portion where a shlieren structure is observed. This protrusion **52** is connected to and integrally formed with a protrusion arrangement **20**A formed on the common-electrode **12**. The relation shown in FIGS. **62**A and **62**B is realized at the portion formed with the protrusion **52**, where the orientation of the liquid crystalline molecules **14** at an edge of the cell electrode coincides with the orientation in the display region, as shown in FIG. **64**. Therefore, the schlieren structure that has been observed in FIG. **58** cannot be observed in FIG. **64** for an improve display quality.

FIG. **255** shows a modification in which the protrusion **52** is arranged to face the edge of the pixel electrode **13**. In this modification, no shlieren structure is observed.

The tenth embodiment, which uses an acrylic transparent resin for the protrusion, can alternatively use a black material. The use of a black resin material can shield the leakage light at the protrusion and therefore improves the contrast. This is also the case with the embodiments described below.

The protrusion **52** which is formed as a non-display region domain regulating means in the non-display region as shown in FIGS. **62**A to **63** can be replaced by a depression (groove) with equal effect. The depression, however, is required to be formed on the TFT substrate.

Any non-display domain regulating means which has an appropriate orientation regulation force can be employed. The direction of orientation is known to change, for example, when the light of a specific wavelength such as ultraviolet light is irradiated on the alignment film. Utilizing this phenomenon, it is possible to realize a non-display region domain regulating means by changing the direction of orientation in a part of the non-display region.

FIGS. **65**A and **65**B are diagrams for explaining the change in orientation direction by irradiation of ultraviolet light. As shown in FIG. **65**A, a vertical alignment film is coated on the substrate surface, and a non-polarized ultraviolet light is irradiated on it from one direction at an angle of, say, 45° as shown in FIG. **65**B. Then, the direction of orientation of the liquid crystalline molecules **14** is known to tilt toward the direction in which the ultraviolet light is irradiated.

FIG. **66** is a diagram showing a modification of the tenth embodiment. The ultraviolet light is irradiated from the direction indicated by arrow **54** on a portion **53** of the alignment film on the TFT substrate opposed to the protrusion **52** constituting the non-display domain regulating means shown in FIG. **63**. As a result, the portion **53** comes to have an orientation regulation force acting in such a direction as to offset the effect of the diagonal electric field at the edge of the cell electrode **13**. Consequently, an effect similar to that of the tenth embodiment shown in FIG. **63** is obtained. The ultraviolet light, though irradiated only on the TFT substrate in FIG. **66**, can alternatively be irradiated only on the CF substrate **16** or on both the TFT substrate and the CF substrate. The direction in which the ultraviolet light is irradiated is required to be set optimally striking a balance between the degree of the orientation regulation force in relation to the irradiation conditions and the orientation regulation force due to the diagonal electric field.

The non-display region domain regulating means, which reduces the effect of the diagonal electric field generated at an edge of the cell electrode on the orientation of the liquid crystalline molecules in the display region and stabilizes the orientation of the liquid crystalline molecules in the display region, is applicable to various systems including the VA system.

Now, desirable arrangements of the protrusions and depressions, which operate as the domain regulating means, which respect to edges of pixel electrodes will be described. FIGS. **67**A to **67**C are 22 diagrams showing fundamental relative positions of the edge of the cell electrode and protrusions acting as domain regulating means. As shown in FIG. **67**A, protrusions **20**B are arranged at the edges of the cell electrode **13**, or a protrusion **20**A is arranged on the common electrode **12** opposed to the edge of the cell electrode **13** as shown in FIG. **67**B. As another alternative, the protrusion **20**A on the CF substrate is formed inside the display region with respect to the edges of the cell electrode **13**, as shown in FIG. **67**C, while the protrusion **20**B on the TFT substrate **17** is arranged in the non-display region.

In FIGS. **67**A and **67**B, the protrusions are arranged at the edges of the cell electrode **13** or in opposed relation thereto, and the region where the protrusions affect the orientation direction of the liquid crystal is defined by the edges. Regardless of the state of the diagonal electric field in the non-display region, therefore, the orientation in the display region is not affected whatsoever. Thus, a stable orientation is secured in the display region and the display quality is improved.

According to the conditions for arrangement shown in FIG. **67**C, the orientation restriction force of the diagonal electric field at an edge of the cell electrode **13** is in the same direction as the orientation regulation force of the protrusions, and therefore a stable orientation can be obtained without developing any domain.

The conditions under which the direction of the orientation regulation force of the diagonal electric field coincides with the direction of the orientation regulation force of the domain regulating means can be realized also using a depression instead of a protrusion.

FIG. **68** is a diagram showing an arrangement of edges and depressions for realizing the conditions for arrangement equivalent to FIG. **67**C. Specifically, the protrusions **25**-**20**B on the TFT substrate **17** are arranged inside the display region, and the protrusions **20**A on the CF substrate are arranged in the non-display region with respect to the edges of the cell electrode **13**.

FIGS. **69**A and **69**B are diagrams showing an arrangement of a linear (striped) protrusion arrangement constituting a domain regulating means on a LCD realizing the conditions FIG. **67**C in the first embodiment. FIG. **69**A is a top plan view and FIG. **69**B is a sectional view. In the configuration of FIGS. **69**A and **69**B, the protrusion height is about 2 μm, the protrusion width is 7 μm and the inter-protrusion interval is 40 μm. After two substrates are attached to each other, the protrusions of the TFT substrate are arranged in a staggered fashion with the protrusions of the CF substrate. In order to realize the conditions of FIG. **67**C, the protrusions of the TFT substrate **17** are interposed between the cell electrodes **13**. Since a gate bus line **31** is interposed between the cell electrodes **13**, however, the protrusion arranged between the cell electrodes **13** is located on the gate bus line **31**.

With the LCD of FIGS. **69**A and **69**B, no undesirable domain is observed and the switching speed is not low at any portion. Therefore, a superior display quality is obtained without any after-image. Assuming that the protrusions **20**B between the cell electrodes **13** in FIGS. **69**A and **69**B are arranged at the edges of the cell electrodes **13**, the conditions of FIG. **67**A can be met, while if the arrangement of the protrusions **20**A and **20**B is reversed between the two substrates, on the other hand, the conditions of FIG. **67**B are satisfied. The protrusion arranged on or in opposed relation to the edges can alternatively be arranged either on the TFT substrate **17** or on the CF substrate **16**. Considering the displacement of the substrates attached to each other, however, the protrusions are desirably formed at the edges of the cell electrodes **13** on the TFT substrate **17**.

FIGS. **70**A and **70**B are diagrams showing an arrangement of a protrusion arrangement of another protrusion pattern for a LCD according to a eleventh embodiment satisfying the conditions of FIG. **67**C. FIG. **70**A is a top plan view and FIG. **70**B is a sectional view. As shown, a checkered grid of protrusions is arranged between the cell electrodes **13**, and protrusions similar in shape to the above-mentioned protrusion pattern are formed sequentially inward of each pixel. By use of this protrusion pattern, the orientation in each pixel can be divided into four directions, but not in equal proportion. Also in this case, the checkered protrusion pattern is arranged on the gate bus line **31** and the data bus line **32** between the cell electrodes **13**.

Also in FIGS. **70**A and **70**B, the conditions of FIGS. **67**A and **67**B are satisfied if the protrusions **20**B otherwise interposed between the cell electrodes **13** are arranged at a portion in opposed relation to an edge of the cell electrode **13** of the TFT substrate **17** or an edge of the CF substrate. In this case, too, the protrusions are preferably formed at the edges of the cell electrode **13** on the TFT substrate **17**.

In the example shown in FIGS. **70**A and **70**B, protrusions are formed in rectangular grid similar to the rectangular cell electrodes. Since the protrusions are rectangular, however, an equal proportion cannot be secured for all the directions of orientation. In view of this, a protrusion arrangement bent in zigzag shown in the ninth embodiment is conceived. As described with reference to FIGS. **58** and **60**, however, an undesirable domain is generated in the neighborhood of the edges of the cell electrode **13** unless protrusions are formed as shown in FIG. **63**. For this reason, independent protrusions for different pixels, not a continuous arrangement of protrusions as shown in FIG. **71**, is the next subject of discussion. In the case where the protrusions **20**A and **20**B are formed as shown in FIG. **71**, however, an abnormal orientation occurs at the portion indicated by T of the pixel **13**, with the result that the difference in distance from an electric field controller (TF) **33** poses the problem of a reduced response rate. With the protrusion arrangement bent in zigzag in a rectangular pixel, it is impossible to satisfy the conditions for arrangement of the protrusions in relation to all the edges of the cell electrode shown in FIGS. **67**A to **67**C. A twelfth embodiment is intended to solve this problem.

FIG. **72** is a diagram showing the shapes of the cell electrode **13**, the gate bus line **31**, the data bus line **32**, the TFT **33** and the protrusions **20**A, **20**B according to the twelfth embodiment. As shown, in the twelfth embodiment, the cell electrode **13** has a shape similar to the bent form of the zigzag protrusions **20**A, **20**B. This shape prevents the occurrence of an abnormal orientation, and the equal distance from the TFT **33** to the end of the cell electrode **13** can improve the response rate. According to the twelfth embodiment, the gate bus line **31** is also bent in zigzag in conformance with the shape of the cell electrode **13**.

As far as the protrusions arranged on the gate bus line **31** are formed on the portions in opposed relation to the edges of the cell electrode **13** or the edges of the CF substrate, the conditions of FIGS. **67**A and **67**B are satisfied. In this case, too, the protrusions are desirably formed at the edges of the cell electrode **13** on the TFT substrate.

Nevertheless, the conditions of FIGS. **67**A to **67**C can be met only for the edges parallel to the gate bus line **31** but not for the edges parallel to the data bus line **32**. As a result, the latter portion is exposed to the effect of the diagonal electric field, thereby posing the problem described above with reference to FIGS. **57**A to **60**.

FIG. **73** is a diagram showing the shapes of the cell electrode **13**, the gate bus line **31**, the data bus line **32**, the TFT **33** and the protrusions **20**A, **20**B according to a modification of the twelfth embodiment. Unlike in the twelfth embodiment of FIG. **72** in which the gate bus line **31** is shaped in zigzag in conformance with the shape of the cell electrode **13**, the cell electrode **13** is shaped as shown in FIG. **73**, so that the gate bus line **31** is rectilinear while the data bus line **32** is bent in zigzag. In FIG. **73**, the protrusions **20**A and **20**B are not independent for different pixels but form a continuous protrusion covering a plurality of pixels. The protrusion **20**B is arranged on the data bus line **32** laid vertically between the cell electrodes **13** thereby to satisfy the conditions of **67**C. The arrangement of FIG. **73** can also realize the conditions of FIGS. **67**A and **67**B, as far as the protrusions arranged on the data bus line **32** are formed in spatially opposed relation to the edges of the cell electrode **13** or the edges of the CF substrate **16**. In this case, too, the

protrusions are desirably formed at the edges of the cell electrode **13** on the TFT substrate **17**.

In the arrangement of FIG. **73**, each protrusion crosses the edge of the cell electrode **13** parallel to the gate bus line **31**. The resulting effect of the diagonal electric field on this portion gives rise to the problem described above with reference to FIGS. **57**A to **60**.

FIG. **74** is a diagram showing another modification of the twelfth embodiment. In the arrangement shown in FIG. **74**, the protrusions are bent twice in a pixel. This makes the pixel somewhat rectangular in shape as compared with FIG. **73** and therefore the display is easier to view.

FIG. **75** is a diagram showing the shapes of the cell electrode **13**, the gate bus line **31**, the data bus line **32**, the TFT **33** and the protrusions **20**A, **20**B according to a thirteenth embodiment. FIGS. **76**A and **76**B are sectional views taken in lines A-A' and B-B' in FIG. **75**. In order to alleviate the effect of the diagonal electric field at the edges of the cell electrode **13** with a protrusion arrangement bent in zigzag, the tenth embodiment includes the non-display region domain regulating means arranged outside the display region while the thirteenth embodiment has the cell electrode bent in zigzag, both having failed to completely eliminate the effect of the diagonal electric field. In view of this, according to the thirteenth embodiment, the portion where the orientation is liable to be disturbed and an undesirable domain is liable to occur as shown in FIGS. **58** and **60** is masked by a black matrix **34** to eliminate the effect of the diagonal electric field on the display.

At the portion A-A' shown in FIG. **75** is free of the effect of the diagonal electric field, the BM **34** is narrowed as shown in FIG. **76**A, while at the portion B-B' where the diagonal electric field has a considerable effect, the width of the BM **34** is increased as compared with the prior art so as not to display any image. In this way, the display quality is not deteriorated nor an after-image or a reduced contrast is caused. The increased area of the BM **34**, however, reduces the luminance of display due to a reduced numerical aperture. Nevertheless, no problem is posed as far as the area of the increase of BM **34** is not considerable.

As described with reference to the tenth to thirteenth embodiments, according to this invention, the effect of the diagonal electric field at the edge portions of the cell electrode can be alleviated and therefore the display quality can be improved.

In the embodiments as set above, the orientation of liquid crystal is divided by the domain regulating means. A detailed observation of the orientation in the boundary portion of the domain, however, reveals the fact that the domain is divided in the directions 180° apart at the domain regulating means, that minute domains 90° different in direction exist in the boundary portion (on a protrusion, a depression or a slit) between domains and that a region looking black exists in the boundary (the neighborhood of the edge of a protrusion, if any) of each domain including a minute domain. The region looking dark brings about a reduced numerical aperture and darkens the display. As described above, the liquid crystal display device using a TFT requires a CS electrode contributing to a reduced numerical aperture. In other cases, a black matrix (BM) is provided for shielding the surrounding of the display pixel electrode and the TFT. In all of these cases, it is necessary to prevent the numerical aperture from being reduced as far as possible.

The use of a storage capacitor with the CS electrode was described above. Let us briefly explain the function of the storage capacitor (CS) and the electrode structure. The circuit of each pixel in a liquid crystal panel having a storage

capacitor is shown in FIG. **77**A. As shown in FIG. **17**, the CS electrode **35** is formed in parallel to the cell electrode **13** in such a manner as to configure a capacitor element between the CS electrode **35** and the cell electrode **13** through a dielectric layer. The CS electrode **35** is connected to the same potential as the common electrode **12**, and therefore, as shown in FIG. **77**A, a storage capacitor **2** is formed in parallel to the capacitor **1** due to the liquid crystal. Upon application of a voltage to the liquid crystal **1**, a voltage is similarly applied to the storage capacitor **2**, so that the voltage held in the liquid crystal **1** is held also in the storage capacitor **2**. As compared with the liquid crystal **1**, the storage capacitor **2** is easily affected by a voltage change of the bus line or the like, and therefore effectively contributes to suppressing an after-image or a flicker and alleviating the display failure due to the TFT-off current. The CS electrode **35** is preferably formed in the same layer as the gate (gate bus line), the source (data bus line) or the drain (cell) electrode of the TFT element in order to simplify the process. Since these electrodes are formed of an opaque metal for securing the required accuracy, the CS electrode **35** is also opaque. As described above, the CS electrode is formed in parallel to the cell electrode **13**, and therefore the portion of the CS electrode cannot be used as a display pixel for a reduced numerical aperture.

The liquid crystal display device is required to have an improved display luminance while an effort is being made to save power consumption at the same time. The numerical aperture, therefore, is preferably as high as possible. As explained above, on the other hand, the light leakage through the slit formed in the protrusion or the electrode for improving the display quality deteriorates the display quality. For eliminating this inconvenience, the protrusion is preferably made of a masking material and the slit is preferably masked with a BM or the like. Nevertheless, these measures contribute to a lower numerical aperture.

An arrangement of the protrusions **20**A, **20**B and the CS electrode **35** of the embodiments as set above is shown in FIG. **77**B. The protrusions **20**A, **20**B and the CS electrode **35** are opaque to the light and the corresponding portions have a lower numerical aperture. The protrusions **20**A, **20**B are formed partly in superposition but partly not in superposition on a part of the CS electrode **35**.

FIGS. **78**A and **78**B are diagrams showing an arrangement of the protrusions **20** (**20**A, **20**B) and the CS electrodes **35** according to a 14th embodiment. FIG. **78**A is a top plan view and FIG. **78**B is a sectional view. As shown, a plurality of CS electrode units **35** are arranged under the protrusions **20**A, **20**B. For a storage capacitor of a predetermined capacitance to be realized, a predetermined area is required of the CS electrode units **35**. The combined area of the five units into which the CS electrode **35** is divided as shown in FIGS. **78**A and **78**B coincides with the area of the CS electrode **35** shown of FIGS. **77**A and **77**B. Further, in view of the fact that the CS electrode units and the protrusions **20**A, **20**B are all superposed one on another in FIGS. **78**A and **78**B, the numerical aperture is not substantially reduced more than it would be reduced by the CS electrode alone. It follows, therefore, that the numerical aperture is not reduced by the provision of the protrusions.

FIGS. **79**A and **79**B are diagrams showing an arrangement of the slits **21** of the electrodes **12**, **13** and the CS electrode units **35** according to a modification of the 14th embodiment. FIG. **79**A is a top plan view and FIG. **79**B is a sectional view. The slits **21** function as a domain regulating means and are preferably masked for preventing the light leakage therethrough. In this modification, the leakage light

at the slits **21** is masked by the CS electrode units **35**. Since the total area of the CS electrode units **35** remains the same, the numerical aperture is not reduced.

FIGS. **80**A and **80**B are diagrams showing an arrangement of the slits **21** of the electrodes **12**, **13**, and the CS electrode units **35** according to another modification of the 11th embodiment. FIG. **80**A is a top plan view and FIG. **80**B is a sectional view. This modification is identical to the aforementioned modification of FIGS. **78**A and **78**B except that the protrusions are bent in zigzag.

FIGS. **81**A and **81**B are diagrams showing an arrangement of the slits **21** of the electrodes **12**, **13**, and the CS electrode units **35** according to another modification of the 14th embodiment. FIG. **81**A is a top plan view and FIG. **81**B is a sectional view. This modification represents the case in which the total area of the protrusions **20**A, **20**B is larger than the total areas of the CS electrode units **35**. According to this modification, the CS electrode units are arranged at positions corresponding to the edges of the protrusions **20**A, **20**B and not arranged at the central portion of the protrusion. As a result, a minute domain having an orientation angle 90° different existing in the neighborhood of the top of the protrusion can be effectively utilized for a brighter display.

The constitution in which the CS electrode is divided into a plurality of CS electrode unit can be adapted to a case in which the depressions (grooves) are used as the domain regulating means.

The 14th embodiment described above can prevent the reduction in numerical aperture which otherwise might be caused by the domain regulating means used.

FIG. **82** shows a protrusion pattern of the fifteenth embodiment. In this fifteenth embodiment, linear protrusions **20**A and **20**B are disposed in parallel with one another on the upper and lower substrates, respectively, so that when they are viewed from the surface of the substrates, these protrusions **20**A and **20**B orthogonally cross one another. The liquid crystalline molecules **14** are oriented perpendicularly to the slopes under the state where no voltage is applied between the electrodes but the liquid crystalline molecules in the proximity of the slopes of the protrusions **20**A and **20**B are oriented perpendicularly to the slopes. Therefore, the liquid crystalline molecules in the proximity of the slopes of the protrusions **20**A and **20**B are inclined under this state and moreover, the directions of inclination are different by 90 degrees near the protrusions **20**A and **20**B. When the voltage is applied between the electrodes, the liquid crystalline molecules are inclined in a direction which is parallel to the substrates, but because the liquid crystalline molecules are regulated in the directions different by 90 degrees near the protrusions **20**A and **20**B, respectively, they are twisted. The change of the image in the case of twisting in this fifteenth embodiment is the same as that of the TN mode shown in FIGS. **2**A to **2**C. FIG. **2**C shows the state when no voltage is applied and this is different only in that when the voltage is applied, the state becomes the one shown in FIG. **2**A. As shown in FIG. **82**, further, four different twist regions are defined in the range encompassed by the protrusions **20**A and **20**B in the fifteenth embodiment. In consequence, viewing angle performance is excellent, too.

Incidentally, the directions of the twists are different among the adjacent regions.

FIGS. **83**A to **83**D explanatory views useful for explaining why the response speed in the fifteenth embodiment is higher than that of the first embodiment. FIG. **83**A shows the state where no voltage is applied, and the liquid crystalline molecules are oriented perpendicularly to the substrates. When the voltage is applied, the liquid crystalline molecules are inclined in such a manner as to twist in the LCD of the fifteenth embodiment as shown in FIG. **83**B. In contrast, the liquid crystalline molecules at other portions are oriented by using the liquid crystalline molecules keeping touch with the protrusions as the trigger in the LCD of the first embodiment as shown in FIG. **83**C. However, the liquid crystalline molecules near the centers of the upper and lower protrusions move irregularly when the orientation changes because they are not limited, and they are oriented in the same direction as shown in FIG. **83**D after the passage of a certain period of time. Generally, the change speed of the twist of the LCDs is high not only in the LCD of the VA system LCD using the protrusions, and the response speed of the fifteenth embodiment is higher than that of the first embodiment.

FIG. **84** shows viewing angle performance of the LCD of the fifteenth embodiment. This viewing angle performance is extremely excellent in the same way as that of the VA LCD of the first embodiment, and is naturally higher than that of the TN mode and is at least equal to that of the IPS mode.

FIG. **85**A is a diagram showing the response speeds with the change of the gray-scale at the 16th graduation, 32nd gradation, 48th gradation, 64th gradation and black (first gradation) when 64-gradation display is effected in the LCD of the fifteenth embodiment. For reference, FIG. **85**B shows the response speed of the TN mode, FIG. **85**C shows the response speed of the mono-domain VA mode in which the orientation is not divided and FIG. **85**D shows the response speed of the multi-domain VA mode using the parallel protrusions of the first embodiment. For example, the response speed from the full black to the full white is 58 ms in the TN mode, 19 ms in the mono-domain VA mode and 19 ms in the multi-domain system, whereas it is 19 ms in the fifteenth embodiment, and this value remains at the same level as those of other VA mode. The response speed from the full white to the full black is 21 ms in the TN mode 12 ms in the mono-domain VA mode and 12 ms in the multi-domain type, whereas it is 6 ms in the fifteenth embodiment, and this value is higher than those of other VA modes. Further, the response speed from the full to the 16th gradation is 30 ms in the TN mode, 50 ms in the mono-domain type and 130 ms in the multi-domain type, whereas it is 28 ms in the fifteenth embodiment, and this value remains at the same level as that of the TN mode and is by far more excellent than the values of other VA modes. The response speed from the 16th gradation to the full black is 21 ms in the TN mode, 9 ms in the mono-domain type and 18 ms in the multi-domain type, whereas it is 4 ms in the fifteenth embodiment and this value is more excellent than the values of any other modes. Incidentally, the response speed of the IPS mode is extremely lower in comparison with any other modes, and the response speeds from the full black to the full white and vice versa are 75 ms, the response speed from the full black to the 16th gradation is 200 ms and the response-speed from the 16 gradation to the full black is 75 ms.

As described above, the LCD of the fifteenth embodiment are extremely excellent in both viewing angle performance and the response speed.

FIGS. **86**A and **86**B shows another protrusion patterns for accomplishing the twist type VA system described above. In FIG. **86**A protrusions **20**A and **20**B are interruptedly disposed in such a fashion as to extend orthogonally in two directions on the respective substrates and not to cross one another, but to cross one another when they are viewed from the respective substrates. In this embodiment, four twist regions are formed in the different way from FIG. **82**. The direction of the twist is the same in each twist region but the

rotating positions deviate from one another by 90 degrees. In FIG. **86**B protrusions **20**A and **20**B are disposed in such a fashion as to extend orthogonally in two directions to the respective substrates and to cross one another but to deviate mutually in both directions. In this embodiment, two twist regions having mutually different twist directions are formed.

In FIGS. **82**, **86**A and **86**B, the protrusions **20**A and **20**B disposed on the two substrates need not be disposed in such a fashion as to orthogonally cross one another. FIG. **87** shows a modification wherein the protrusions **20**A and **20**B shown in FIG. **82** are so disposed as to cross one another at an angle other than 90 degrees. In this case, too, four twist regions having mutually different twist directions are formed, and the quantity of the twist is different between the two opposed regions.

Furthermore, the same result can be obtained when slits are disposed in place of the protrusions **20**A and **20**B shown in FIGS. **82**, **86**A and **86**B.

In the fifteenth embodiment shown in FIG. **82**, there is no means for controlling the orientation at the center portion in the frame encompassed by the protrusions **20**A and **20**B in comparison with the portions near the protrusions, and the orientation is likely to be disturbed because it is far from the protrusions. For this reason, an elongated time is necessary before the orientation gets stabilized, and it is expected that the response speed at the center portion becomes lower. The response speed attains the highest at the corner portions of the frame because they are affected strongly by the protrusions serving as two adjacent sides. The influences of the orientation at the corner portions are transferred to the center portion, impinge with the influences of other twist regions and the twist regions are rendered definite and are stabilized. In this way, all the liquid crystals are not simultaneously oriented, but certain portions are first oriented and then this orientation is transmitted to the portions nearby. Therefore, the response speed becomes slower at the center portion far from the protrusions. When the frame defined by crossing is a square as shown in FIG. **82** for example, the influences are transferred from the four corners but when the frame defined by the crossing protrusions is the parallelogram as shown in FIG. **87**, the influences are transferred from the acute angle portions, where the influences of the protrusions are stronger, to the center portion. The influences impinge at the center portion and are further transferred to the corners having an obtuse angle. Therefore, the response speed becomes slower in the parallelogramic frame than in the square frame. To solve such a problem, a protrusion **20**D similar to the frame is disposed at the center of each frame as shown in FIG. **88**. An excellent response speed can be obtained when, for example, the protrusions **20**A and **20**B has a width of 5 μm and a height of 1.5 μm, the gap of the protrusions is 25 μm and the protrusion **20**D is a square pyramid having a bottom of 5 μm.

FIG. **89** shows another embodiment wherein the protrusion is disposed at the center of each frame of the protrusion pattern shown in FIG. **87**. The same result as that of FIG. **82** can be obtained according to this arrangement, too.

In the constructions shown in FIGS. **82**, **86**A, **86**B and **87** wherein the protrusions **20**A and **20**B cross one another, the thickness of the liquid crystal layer can be limited at the portions at which the protrusions **20**A and **20**B cross one another by setting the sum of the height of the protrusions **20**A and **20**B to a value equal to the gap of the substrates, that is, the thickness of the liquid crystal layer. According to this arrangement, the spacer need not be used.

FIGS. **90**A and **90**B are diagrams showing the structure of a panel of the 16th embodiment. FIG. **90**A is a side view, and FIG. **90**B is an oblique view of a portion of the panel corresponding to one square of a lattice. FIG. **91** is a diagram showing-a pattern of protrusions in the 16th embodiment which is seen in a direction vertical to the panel. As illustrated, in the 16th embodiment, the protrusions **20**A are created like a cubic lattice on the electrode **12** formed on one substrate, and the pyramidal protrusions **20**B are created at positions coincident with the center positions of the opposite squares of the lattice on the electrodes on the other substrate. In a region shown in FIG. **90**B, the orientation is divided according to the principles described in conjunction with FIG. **12**B and divided vertically and laterally uniformly. In reality, a prototype was produced by setting the distance between the electrodes to 3.5 micrometers, the sideways spacing between protrusions **20**A and **20**B to 10 micrometers, and the height of protrusions to 5 micrometers. As a result, the viewing angle characteristic of the panel was of the same level as the one of the panel of the second embodiment shown in FIG. **22**.

FIGS. **254**A and **254**B show a modification of the sixteenth embodiment. FIG. **254**A shows a protrusion pattern and FIG. **254**B is a sectional view. In this modification, the arrangement of the matrix-like protrusions and the pyramidal protrusions of the sixteenth embodiment is reversed. In other words, the protrusion **20**A disposed on the electrode **12** of the CF substrate **16** is pyramidal whereas the protrusion **20**B on the side of the TFT substrate **17** has a two-dimensional matrix form. The protrusion **20**A is disposed at the center of each pixel **9** and the protrusion **20**B is disposed in the same pitch as that of the pixels and is disposed on the bus line between the pixels **9**. Therefore, the liquid crystal is oriented in four directions inside each pixel. The domain is divided by the protrusion **20**A at the center of the pixel as shown in FIG. **254**B. The protrusion **20**B disposed outside the pixel electrode **13** divides the orientation at the boundary of the pixels as shown in the drawing. Further, the edge of the pixel electrode functions at this portion as the domain regulating means. The orientation regulating force by the protrusion **20**B and the orientation regulating force of the edge of the pixel electrode coincide with each other. Consequently, the division of the orientation can be carried out stably. In this modification, the distances between the protrusion **20**A and the protrusion **20**B versus the edge of the pixel electrode **12** are great. Therefore, it is only the protrusion **20**A that exists inside the pixel, and the occupying area of the protrusion inside the pixel is small and display luminance can be improved, though the response speed drops to a certain extent. Further, the production cost can be reduced by forming the protrusion **20**B by the formation process of the bus line because the number of the production steps does not increase.

In the aforesaid first to 16th embodiments, protrusions produced using a resist that is an insulating material are used as a domain regulating means for dividing the orientation of a liquid crystal. In the embodiments, the shape of the inclined surfaces of the protrusions are utilized. The insulating protrusions are very important in terms of the effect of interruption of electric fields. A liquid crystal is driven using, generally, an alternating wave. With an increase in response speed deriving from innovation of a liquid crystal material, influence exerted during one frame (during which a direct (dc) voltage is applied), that is, influence predetermined by a DC wave must be taken into full consideration. A driving wave for a liquid crystal must exhibit both the characteristics of the AC and DC voltages and satisfy the requirements for

the AC and DC voltages. The properties of the resist used to allow the driving wave for a liquid crystal to exert a predetermined effect of minimizing electric fields must be set in relation to the characteristics of the AC and DC voltages or the AC and DC characteristics. Specifically, the resist must be set to have properties effective in minimizing electric fields in relation to the AC and DC characteristics.

From the viewpoint of the DC characteristic, the specific resistance ρ must be high enough to affect the resistance of a liquid-crystal layer. Specifically, the specific resistance must be 10^{12} ohms/cm or more so that it will be equal to or larger than the specific resistance of a liquid crystal (for example, the specific resistance of a TFT-drive liquid crystal is about 10^{12} ohms/cm or more). Preferably, the specific resistance should be 10^{13} ohms/cm or more.

From the viewpoint of the AC characteristic, the capacitance (value determined by a dielectric constant, film thickness, and sectional area) of a resist must be about ten or less times larger than the capacitance of a liquid-crystal layer under the resist (with an impedance of about one-tenth or more of the impedance of the liquid-crystal layer), so that the resist can exert the operation of minimizing electric fields in the liquid-crystal layer under the resist. For example, the dielectric constant ∈ of the resist is approximately 3 or about one-third of the dielectric constant ∈ of the liquid crystal layer (approximately 10). The film thickness is approximately 0.1 micrometers or about 1/35 of the thickness of the liquid-crystal layer (for example, approximately 3.5 micrometers). In this case, the capacitance of the insulating film is approximately ten times larger than the capacitance of the liquid-crystal layer under the insulating film. In other words, the impedance of the resist (insulating film) is approximately one-tenth of the impedance of the liquid-crystal layer under the resist. Thus, the resist can affect the distribution of electric fields in the liquid-crystal layer.

In addition to an effect exerted by the shape of the inclined surfaces created by the resist, the influence of the distribution of electric fields can be utilized. This results in more stable and firm alignment. When a voltage is applied, liquid crystalline molecules are tilted. At this time, the strength of electric fields in a domain in which the orientation of a liquid crystal is divided (on a resist) is sufficiently low. In the domain, liquid crystalline molecules aligned nearly vertically exist stably and work as a barrier (partition) against domains generated on both sides of the domain. When a higher voltage is applied, the liquid crystalline molecules in the orientation-divided domain (on the resist) starts tilting. However, the liquid crystalline molecules in the domains generated on both sides of the domain on the resist tilt in a direction nearly horizontal to the resist (this results in a very firm orientation). For establishing this state, the insulating layer (resist) of the orientation-divided domain must have a capacitance that is approximately ten or less times larger than the one of the liquid-crystal layer under the resist. A material exhibiting a small dielectric constant ∈ should be adopted to realize the insulating layer, and the thickness of the layer must be large. This suggests an insulating layer having a dielectric constant ∈ of approximately 3 and a thickness of 0.1 micrometers or more. The employment of an insulating layer having a smaller dielectric constant ∈ and a larger thickness would exert a more preferable operation and effect. In the first to 16th embodiments, a novolak resist having a dielectric constant ∈ of approximately 3 is used to form protrusions of 1.5 micrometers thick. Observation of orientation division has revealed that very stable alignment can be attained. The novolak resist is widely adopted in the process of manufacturing a TFT or CF. The adoption of the novolak resist would bring about a great merit (of obviating the necessity of additional facilities).

Moreover, it is ascertained that the novolak resist is highly reliable as compared with other resists or a flattening material and has no problem.

Moreover, when the insulating film is placed on both substrates, a more preferable operation and effect can be exerted.

Aside from the novolak resist, an acrylic resist (∈=3.2) was checked to see if it would prove effective as an insulating film. The same results as those obtained by checking the novolak resist were obtained. For demonstrating that the influence of electric fields is very important, an ITO film was deposited on a resist and the aligned-state of liquid crystalline molecules was observed. The results were not so good as those obtained when the insulating film was used.

In the first to 16th embodiments, an electrode is slitted or protrusions of insulators are formed on an electrode in order to divide the orientation of a liquid crystal. Other forms can be adopted. Some of the forms will be presented below.

FIGS. **92**A and **92**B are diagrams showing the structure of a panel of the 17th embodiment. FIG. **92**A is an oblique view and FIG. **92**B is a side view. As illustrated, in the 17th embodiment, protrusions **50** extending parallel to one another unidirectionally are formed on glass substrates **16** and **17**, and electrodes **12** and **13** are formed on the substrates. The protrusions **50** are arranged to be mutually offset by a half pitch. The electrodes **12** and **13** are therefore shaped to partly jut out. The surfaces of the electrodes are processed for vertical alignment. Using the thus shaped electrodes, when a voltage is applied to the electrodes, electric fields are induced in a vertical direction. The orientation of a liquid crystal is divided into two directions with each protrusion as a border. The viewing angle characteristic of the panel is therefore improved as compared with a conventionally exhibited one. However, the distribution of electric fields becomes different from the one attained when the protrusions are made of an insulating material. Only the effect of the shape of the inclined surfaces of the protrusions is utilized in order to divide the orientation. The stability of alignment is slightly inferior to that attained when the protrusions are made of an insulating material. However, as described above, the protrusions provided on the electrodes need to be made of insulating material with low dielectric constant. Therefore, the materials used to form the protrusions are limited. Further, various conditions must be satisfied to form the protrusions by using those materials. This causes a problem in the production process. Contrarily, the panel structure of the 17th embodiment does not have such limitation.

FIG. **93** is a diagram showing the structure of a panel of the 18th embodiment. In this embodiment, insulating layers **61** formed on the ITO electrodes **12** and **13** are provided with depressions **23**. As the shape of the depressions, the shapes of protrusions or slits of electrodes presented in the second to ninth embodiments can be adopted. In this case, an effect exerted by oblique electric fields works like the effect exerted by the protrusions to stabilize alignment.

FIG. **94** shows a panel structure of the nineteenth embodiment. In this embodiment, electrodes **12** and **13** are formed on glass substrates **16** and **17**, respectively, layers **62** each made of an electrically conductive material and having a depression (groove) **23**A, **23**B having a width of 10 μm and a depth of 1.5 μm are formed on these electrodes **12** and **13**, and vertical alignment films **22** are formed on these layers

62. Incidentally, the thickness of a liquid crystal layer is 3.5 μm, and a color filter layer **39**, a bus line, a TFT, etc, are omitted from the drawing. It can be observed that the orientation of the liquid crystal is divided at the recess portions. In other words, it has been confirmed that the depression, too, functions as the domain regulating means.

In the panel structure of the nineteenth embodiment, the depressions **23**A and **23**B are disposed at the same predetermined pitch of 40 μm in the same way as in the case of the protrusions, and the upper and lower depressions **23**A and **23**B are so disposed as to deviate by a half pitch. Therefore, the regions in which the liquid crystal assumes the same orientation are defined between the adjacent upper and lower depressions.

FIG. **95** shows the panel structure of the 20th embodiment. In this 20th embodiment, layers **62** having grooves **23**A and **23**B having a width of 10 μm and a depth of 1.5 μm are formed on the glass substrates **16** and **17** by using a color filter (CF) resin, respectively, electrodes **12** and **13** are formed on these layers **62**, and vertical alignment films are further formed on the electrodes **12** and **13**, respectively. In other words, a part of each electrode **12**, **13** is recessed. The protrusions **23**A and **23**B are disposed at the same predetermined pitch of 40 μm whereas the upper and lower depressions **23**A and **23**B are so disposed as to deviate from one another by a half pitch. In this case, too, the same result as that of the nineteenth embodiment can be obtained. Incidentally, since the structure having the depression is disposed below the electrode in this 20th embodiment, limitation to the material is small, and the material used for other portions such as the CF resin can be used.

In the case of the protrusion and the slit, the orientation is divided in such a fashion that the liquid crystalline molecules expand in the opposite direction at these portions but in the case of the recess, the orientation is divided in such a fashion that the liquid crystalline molecules face one another at the depression portion. In other words, the function of dividing the orientation by the recess has the opposite relation to that of the protrusion and the slit. Therefore, when the depression is used as the domain regulating means in combination with the protrusion or the slit, the preferred arrangement becomes opposite to the arrangements of the foregoing embodiments. The explanation will be predetermined next on the arrangement when the recess is used as the domain regulating means.

FIG. **96** shows an example of the preferred arrangements when the depression and the slit are used in combination. As shown in the drawing, the slits **21**A and **21**B are disposed at positions opposing the depressions **23**A and **23**B of the 20th embodiment shown in FIG. **95**. Since the direction of the orientation division of the liquid crystal by the depressions and the slits opposing one another is the same, the orientation is further stabilized. For example, when the depression is formed under the condition of the 20th embodiment, the slit has a width of 15 μm and the gap between the center of the depression and that of the slit is 20 μm, the switching time is 25 ms under the driving condition of 0 to 5 V and 40 ms under the driving condition of 0 to 3 V. In contrast, when only the slit is used, the switching time is 50 ms and 80 ms, respectively.

FIG. **97** shows the structure wherein the depression **20**A and the slit **21**A on one of the substrates (substrate **16** in this case) in the panel structure shown in FIG. **98**, and the region having the same orientation direction is formed between the adjacent depression **20**B and the slit **21**B.

Incidentally, the same characteristics can be obtained by disposing the protrusion at the same position in place of the slit in the panel structures shown in FIGS. **96** and **97**, and the response speed can be further improved.

FIG. **98** shows another panel structure wherein the depression **23**B is formed in the electrode **13** of the substrate **17** and the protrusions **20**A and the slits **21**A are alternately formed at positions of the opposed substrate **16** at positions facing the depression **23**B, respectively. In this case, the direction of the orientation becomes different between the set of the adjacent depression **23**B and protrusion **20**A and the set of the adjacent depression **23**B and slit **21**A and consequently, the boundary of the orientation regions is formed in the proximity of the center of the depression.

FIGS. **99**A and **99**B are diagrams showing the structure of a panel of the 21th embodiment. As illustrated, the panel of the 21th embodiment is a simple matrix LCD. The surface of each electrode is dented. The orientation of a liquid crystal is divided with each depression as a border. However, like the tenth embodiment, an effect of oblique electric fields is not exerted. The stability of alignment is little poor.

As described above, the alignment dividing operation of depressions (grooves) is reversed to those of protrusions and slits. By using this relation, a ratio of domain areas can be constant regardless of assembly errors. Now, the influence of assembly errors in the panel of the first embodiment will be described.

FIGS. **100**A and **100**B are sectional views of a panel in the first embodiment. As described already, a region where the orientation is regulated is defined by the protrusion **20**A formed on the common electrode **12** and the protrusion **20**B formed on the cell electrode **13**. In FIG. **100**A, the region defined by the right inclined side surface of the protrusion **20**B and the left inclined side surface of the protrusion **20**A is designated as a region A, and the region defined by the left inclined side surface of the protrusion **20**B and the right inclined side surface of the protrusion **20**A is designated as a region B.

Assume that the CF substrate **16** is displaced leftward of the TFT substrate **17** due to an assembly error, as shown in (**2**) FIG. **100**B. The region A is reduced, while the region B increases. Therefore, the ratio between region A and region B is not already 1 to 1. The resulting proportion of liquid crystalline molecules divided in orientation is not equal, thereby deteriorating the viewing angle characteristic.

FIGS. **101**A and **101**B are sectional views of a panel according to a 22th embodiment. In the 22th embodiment, as shown in FIG. **101**A, a depression **22**B and a protrusion **20**B are formed in the TFT substrate **17**, followed by forming a depression **20**A and a protrusion **22**A on the CF substrate **16**. This process is repeated. As shown in FIG. **101**B, assuming that the CF substrate is displaced with respect to the TFT substrate **17** at the time of assembly, the region A' defined by the protrusions **20**B and **20**A is reduced. Since the region A" defined by the depressions **22**B and **22**A is increased by the same amount as the region A' is reduced, however, the region A remains unchanged. The region B, which is defined by the protrusion **20**B, the depression **22**B, the protrusion **20**A and the depression **22**A, remains unchanged since the interval between them remains unchanged. Consequently, the ratio between the regions A and B remains the same, and the superior viewing angle characteristic is maintained.

FIG. **102** is a sectional view of a panel according to a 23th embodiment. In the 23th embodiment, as shown, the CF substrate **16** is formed with the protrusions **22**A and the depressions **20**A alternately with each other. This process is repeated. The region A is defined by the left inclined side surface of the protrusion **20**A and the right inclined side surface of the depression **22**A, while the region B is defined

by the right inclined side surface of the protrusion **20**A and the left inclined side surface of the depression **22**A. In view of the fact that the orientation region is defined only by the protrusions and depressions formed on one of the substrates, the assembly accuracy is not affected.

The foregoing embodiments are directed to obtain a great viewing angle in all directions. Depending on the application of the liquid crystal panel, however, there are the cases where the viewing angle need not be great, and a great viewing angle needs be obtained in only a specific direction. The LCD suitable for such an application can be accomplished by using the orientation dividing technology by the domain regulating means described above. Next, several embodiments to which the technology of the present invention is applied for the LCDs for such specific applications will be explained.

FIGS. **103**A and **103**B show the panel structure of the 24th embodiment. FIG. **103**A is a top view and FIG. **103**B is a sectional view taken along a line Y-Y' of FIG. **103**B. Linear protrusions **20**A and **20**B are disposed in the same pitch on substrates **16** and **17**, respectively, as shown in the drawing, and these protrusions **20**A and **20**B are so situated as to deviate a little from the respective opposing positions. In other words, the region B is extremely narrowed in the structure shown in FIG. **102** so that the regions are occupied almost fully by the region A.

The panel of the twenty-fourth embodiment is used for a protrusion type LCD, for example. The viewing angle performance of the protrusion type LCD may be narrow, but a high response speed, a high contrast and high luminance are required for the protrusion type LCD. Since the orientation direction of the panel of the 24th embodiment is substantially in one direction (mono-domain), the viewing angle performance is the same as those of the conventional VA system and cannot be said as excellent. Nonetheless, since the protrusions **20**A and **20**B are disposed, the response speed is improved markedly in comparison with the conventional system, in the same way as the LCDs of the foregoing embodiments. As to contrast, the contrast of this panel is substantially equal to other VA system and is therefore superior to that of the conventional TN mode and IPS mode. As has been explained already with reference to FIG. **27**, the orientation gets distorted and leaking light transmits through the portions of the protrusions **20**A and **20**B. To improve contrast, therefore, the portions of these protrusions **20**A and **20**B are preferably shaded. As to luminance, on the other hand, the aperture ratio of the pixel electrode **13** is preferably increased. Therefore, the protrusions **20**A and **20**B are disposed at the edge of the pixel electrode **13** as shown in FIGS. **103**A and **103**B. This arrangement can increase luminance without lowering the aperture ratio.

From the aspect of the response speed, the gap between the protrusions **20**A and **20**B is preferably decreased but to attain this object, the protrusions **20**A and **20**B must be disposed around the pixel electrode **13**. When the protrusions **20**A and **20**B are disposed around the pixel electrode **13**, these portions must be shaded, so that the aperture ratio drops as much. As described above, the response speed, the contrast and luminance have the trade-off relationship, and they must be set appropriately depending on the object of use, and so forth.

FIG. **104** shows a structure for achieving an LCD panel having excellent viewing angle performance in three directions by utilizing the technology of forming the mono-domain according to the 24th embodiment. In this structure, the protrusions **20**A and **20**B are disposed in such a fashion as to define two regions of the transverse direction in the same proportion and one region of the longitudinal orientation inside one pixel. The two regions of the transverse orientation in the same proportion are formed by so disposing the protrusions **20**A and **20**B as to deviate from one another by a half pitch as shown in FIGS. **100**A and **100**B, while one region of the longitudinal orientation is formed by disposing the protrusions **20**A and **20**B adjacent to one another as shown in FIGS. **103**A and **103**B. This structure can accomplish a panel which has excellent viewing angle performance on the right and left sides and on the lower side but has lower viewing angle performance on the upper side.

The LCD such as of the 24th embodiment is used for a display which is installed at a high position so that a large number of people look it up from below, such as a display device disposed above a door of a train.

As shown in FIG. **85**C, the LCD of the VA system which does not execute the orientation division and the LCD of the VA system which execute the orientation division by the protrusions or the like, the response speed from black to white and vice versa is superior to that of the TN mode, but the response speed between the intermediate gray-scale is not practically sufficient. The twenty-fifth embodiment solves this problem.

FIGS. **105**A and **105**B show the panel structure in the 25th embodiment. FIG. **105**A shows the shape of the protrusion when viewed from the panel surface and FIG. **105**B is a sectional view. As shown in these drawings, the position of the protrusion **20**B is charged inside one pixel so as to define a portion having a different gap with the protrusion **20**A. In consequence, the proportion of the domain oriented in two directions can be made equal and the viewing angle performance is symmetric. When the structure shown in the drawings is employed, the response speed between the intermediate gray-scale can be apparently improved. This principle will be explained with reference to FIGS. **106** to **109**B.

FIG. **106** shows the structure of the panel manufactured for measuring the changes of the response speed and the transmittance depending on the gap of the protrusions. The protrusions **20**A and **20**B have a height of 1.5 μm and a width of 10 μm, and the thickness of the liquid crystal layer is 3.5 μm. The response speed and the transmittance of the region of the gap d**1** and the region of the gap d**2** are measured by setting one of the gaps d**1** of the protrusions to 10 μm, changing the other gap d**2** and changing also the voltage to be applied across the electrodes between 0V and 3 V corresponding to the intermediate gray-scale.

FIG. **107** is a graph showing the result of the response speed measured in the way described above. This graph corresponds to the one obtained by extracting the object portion shown in FIGS. **20**A and **20**B. As can be seen clearly from the graph, the response time drops as the gap d**2** becomes smaller.

FIG. **108**A shows the change of the transmittance when the applied voltage is changed, by using the gap d**2** as a parameter. FIG. **108**B shows the change of the transmittance when the voltage is changed from 0V to 3V by using the gap d**2** as a parameter. It can be seen from FIGS. **108**A and **108**B that the response speed of the intermediate gradation can be drastically improved by decreasing the gap d**2** of the protrusions. However, the maximum transmittance drops when the gap d**2** of the protrusions is decreased.

FIG. **109**A is a graph showing the normalized time change of the transmittance at each gap d**2**, and FIG. **109**B explains the orientation change of the liquid crystal. Assuming that the time before the transmittance reaches 90% of the maxi-

mum transmittance is an ON response time, the ON response time when d**2** is 10 μm is Ton **1**, the ON response time when d**2** is 20 μm is Ton **2** and the ON response time when d**2** is 30 μm is Ton **3**, they have a relationship of Ton **1**<Ton **2**<Ton **3**.

The reason why such a difference occurs is because only the liquid crystals in the proximity of the protrusion are oriented perpendicularly to the slope of the protrusion and the liquid crystals away from the protrusion are oriented perpendicularly to the electrode when the voltage is not applied, as shown in FIG. **109**B. When the voltage is applied, the liquid crystal is inclined, and the liquid crystal can take the tilt angle of up to 360 degrees with respect to the axis perpendicular to the electrode. The liquid crystal in the proximity of the protrusion is oriented when the voltage is not applied, and the liquid crystal between the protrusions is oriented in such a fashion as to extend along the former liquid crystal as the trigger. In this way is formed the domain in which the liquid crystals are oriented in the same direction. Consequently, the closer to the liquid crystal to the protrusion, the more quickly it is oriented.

As described above, the response time between black and white is sufficiently short in the existing VA system LCDs and it is the response time between the intermediate grayscale that becomes the problem. In the case of the structure shown in FIGS. **105**A and **105**B, the transmittance in the regions having a narrow gap d**2**" changes within a short time whereas the transmittance in the regions having a broad gap d**2**' changes gradually. The regions of the gap d**2**" are narrower than the regions of the gap d**2**' and have a smaller contribution to the transmittance, but because the human eyes have logarithmic characteristics, the human eyes catch the change as a relatively large change when the transmittance in the regions of the small gap d**2**" changes a little. Therefore, if the transmittance of the regions having a small gap d**2**" changes within a short time, this change is caught as the drastic change as a whole.

As described above, the panel according to the 25th embodiment can apparently improve the response speed between the intermediate gray-scale without lowering the transmittance.

FIG. **110** shows the panel structure of the 26th embodiment. As shown in the drawing, the protrusions **20**A and **20**B are disposed in an equal pitch on the substrates **16** and **17** and the electrodes **12** and **13** are formed on the protrusions, respectively, in this 26th embodiment. However, the electrodes are not formed on one of the slopes of the protrusions **20**A and **20**B, and a vertical alignment film is further formed. The protrusions **20**A and **20**B are arranged in such a fashion that the slopes on which the electrode is formed and the slopes on which the electrode is not formed are adjacent to one another. In the region between the slopes on which the electrodes are not formed, the liquid crystals are oriented perpendicularly to the slopes, and the orientation direction is decided consequently. The electric field in the liquid crystal layer is represented by broken lines in the drawing. Since the liquid crystals are oriented along this electric field, the orientation direction due to the electric field in the proximity of the slopes, on which the electrodes are not formed, coincides with the orientation direction due to the slopes.

In the region between the slopes on which the electrode is formed, on the other hand, the liquid crystal in the proximity of the slopes is oriented perpendicularly to the slopes, but the orientation direction of the electric field in this region is different from the orientation direction due to the slopes. Therefore, the liquid crystal in this region is oriented along the electric field with the exception of the portions near the slopes when the voltage is applied. Consequently, the orientation directions in the two regions become equal to each other, and the mono-domain orientation can be obtained.

FIG. **111** shows the viewing angle performance with respect to contrast when a phase difference film having negative dielectric constant anisotropy and having the same retardation as that of the liquid crystal panel is superposed with the panel of the 26th embodiment. A high contrast can be obtained over a broad range of viewing angles. Incidentally, when this panel is assembled into the protrusion type projector, the contrast ratio is at least 300. Incidentally, the contrast ratio obtained when the ordinary TN mode LCD is assembled into the protrusion type projector is about 100, and it can be appreciated that the contrast ratio can be drastically improved.

In the case where a liquid crystal display device having a configuration with a protrusion pattern is driven as in the first embodiment, the display quality is seen to deteriorate in the neighborhood of the bus line (gate bus line or data bus line) in the pixel. This is due to the undesirable minute region (domain) formed in the neighborhood of the bus line and the resulting disturbance of liquid crystal orientation and reduced response rate. The problem thus is posed of a reduced viewing angle characteristic and a reduced color characteristic in half tone. This problem is solved in a 27th Embodiment.

FIG. **112** is a diagram showing an example pattern for repeating the linear protrusions according to the embodiments as set above. The protrusion pattern described above has a plurality of protrusions of a predetermined width and a predetermined height repeated at predetermined pitches. In FIG. **112**, therefore, the width l and the interval m assume of the protrusion assume the predetermined values of **11** and m**1**, respectively. In the shown example, the width of the protrusion formed on one substrate is different from that of the protrusion formed on the other substrate. The protrusions formed on a substrate, however, have a predetermined width l. This is also the case with the protrusion height h.

FIG. **113** is a diagram showing the wavelength dispersion characteristic of the optical anisotropy of the liquid crystal used. As shown, it is seen that the shorter the wavelength, the larger the retardation Δn. Thus, the retardation Δn increases in the order of blue (B) pixel, green (G) pixel and red (R) pixel, and different colors have different retardation Δn while passing through the liquid crystal layer. This difference is desirably as small as possible.

FIG. **114** is a diagram showing a protrusion pattern according to a 27th embodiment of the invention. In the 27th embodiment, the blue (B) pixel **13**B, the green (G) pixel **13**G and the red (R) pixel **13**R each have the same protrusion width l but different protrusion intervals m. Specifically, the B pixel **13**B has m**1**, the G pixel **13**G m**2** and the R pixel **13**R m**3** in such a relation that m**1**>m**2**>m**3**.

The smaller the protrusion interval m, the larger the effect that the electric field vector has on the liquid crystalline molecules, thus making it more possible to alleviate the problem of the electric field vector at the time of drive. FIG. **115** is a diagram showing the relation between the applied voltage and the transmittance as measured while changing the protrusion interval. It is seen that the larger the interval m, the larger the numerical aperture, and hence the transmittance is improved. The wavelength dispersion characteristic of the optical anisotropy of the liquid crystal is as shown in FIG. **113**. By changing the protrusion interval m for each color pixel as shown in FIG. **114**, the difference of

the retardation for a particular color can be reduced Δn while passing through the liquid crystal layer for an improved color characteristic.

FIG. **116** is a diagram showing a protrusion pattern according to a 28th embodiment of the invention. In the seventh embodiment, the blue (B) pixel **13**B, the green (G) pixel **13**G and the red (R) pixel **13**R have the same protrusion interval m but different protrusion widths l. The effect is the same as that of the 27th embodiment.

FIG. **117** is a diagram showing a protrusion pattern according to an 29th embodiment of the invention. In the 29th embodiment, the protrusion interval m in each pixel is set to a small value m**1** in the upper and lower regions near to the gate bus line and a large value m**2** at the central region. In the neighborhood of a bus line such as the gate bus line or the data bus line, a domain may occur at the time of driving and the liquid crystalline molecules fall into a state not suitable for display due to the electrical field vector, thereby deteriorating the display quality. According to the eighth embodiment, the protrusion interval is narrowed in the region near to the gate bus line thereby to make it difficult for the gate bus line to be affected by the electrical vector. As a result, the generation of an undesirable domain is suppressed for an improved display quality. However, a narrower protrusion interval reduces the numerical aperture accordingly and darkens the display. From the viewpoint of numerical aperture, therefore, a larger protrusion interval is recommended. The protrusion pattern according to the eighth embodiment can minimize the reduction in numerical aperture and reduce the effect of the electrical field vector generated by the gate bus line.

FIG. **118** is a diagram showing the pixel structure in the case where the protrusion pattern according to the 29th embodiment shown in FIG. **117** is actually realized.

FIG. **119** is a diagram showing a protrusion arrangement according to a 30th embodiment. As shown in FIG. **119**, in the 30th embodiment, the protrusion height is changed gradually.

FIG. **120** is a diagram showing the change that the relation between the applied voltage and the transmittance undergoes when the protrusion height is changed, FIG. **121** the change that the relation between the applied voltage and the contrast undergoes when the protrusion height is changed, FIG. **122** the change of the transmittance in white level with respect to the protrusion height, and FIG. **123** the change of the transmittance in black level with respect to the protrusion height. These diagrams show the result of measuring the transmittance and the contrast in test equipment with the width and interval of the resist for forming the protrusion set to 7.5 μm and 15 μm, respectively, the cell thickness to about 3.5 μm, and the resist height to 1.537 nm, 1.600 nm, 2.3099 nm and 2.486 nm.

This measurement shows that the transmittance of white level (with 5 V applied) increases with the resist height. This is considered due to the fact that the protrusion playing an auxiliary role in tilting the liquid crystal is so large that the liquid crystal is positively fallen. The transmittance (leakage light) in black level (without any applied voltage) also increases with the protrusion height. This is not desirable as it works to deteriorate the black level. The contrast (ratio between white luminance and black luminance) decreases with the protrusion height. It is therefore desirable to use a masking material for the protrusion and not to increase the protrusion height excessively.

Any way, the orientation of the crystal liquid can be changed by changing the protrusion height, and therefore a superior display is made possible by changing the protrusion height for each color pixel and thus adjusting the color characteristic, or by setting the protrusion height appropriately in accordance with the distance from the bus line. For the R pixel, for example, the protrusion height is increased, and decreased for the G pixel and the B pixel in that order, or in each pixel, the protrusion height is increased in the neighborhood of the bus line and lowered at the central portion.

The inventor has confirmed that the screen display can be accomplished without any problem even when the protrusion height is increased to the same level as the cell thickness. As a result, the protrusion height is set to the same level as the cell thickness as shown in FIG. **124**A, or protrusions are formed at the opposed positions on the two substrates as shown in FIG. **124**B so that the sum of the heights of the two protrusions is the same as the cell thickness. In this way, the protrusion can play the role of a panel spacer.

FIGS. **125**A and **125**B are diagrams showing a protrusion pattern according to a 31th embodiment. In this embodiment, as shown in FIG. **125**A, the inclination of the side surfaces of the protrusion is defined by the angle θ that the side surface forms with the substrate (electrode). This angle is called the taper angle. According to the tenth embodiment, assume that the taper angle θ of the protrusion **20** can take several values as shown in FIG. **125**B. Generally, the larger the taper angle θ, the more satisfactory the orientation into which the liquid crystalline molecules fall. By changing the taper angle θ, therefore, the orientation of the liquid crystal can be changed. Thus, a superior display can be made possible by changing the taper angle for each color pixel to adjust the color characteristic or by setting a proper taper angle θ in accordance with the distance from the bus line. For example, the taper angle θ is set large for the R pixel, and decreased for the G pixel and the B pixel in that order. Also, the taper angle θ is increased in the neighborhood of the bus line and decreased at the central portion in a pixel.

As described above with reference to the sixth to tenth embodiments, the orientation regulation force of the protrusion is changed by changing the protrusion interval, protrusion width, protrusion height or taper angle. It is therefore possible that these conditions are differentiated within a pixel or with different color pixels to partially differentiate the orientation regulation force of protrusions and thus to assure the viewing angle characteristic or response rate of the liquid crystal as near to the ideal ones as possible.

Retardation of the liquid crystal depends on the wavelength as shown in FIG. **113**. Therefore, an embodiment of the liquid crystal panel which improves luminance of white display on the basis of this feature and accomplishes a high response speed for all the color pixels will be explained.

First, wavelength dependence of the VA system will be explained briefly. FIG. **126** shows the change of a twist angle of a liquid crystal layer due to the application of a voltage when a vertical orientation (VA) system liquid crystal display panel using a liquid crystal having negative dielectric anisotropy (n type liquid crystal) is provided with the twist angle. When no voltage is applied, the liquid crystal is oriented in a direction of 90 degrees on the surface of one of the substrates and in a direction of 0 degree on the surface of the other substrate, so that the twist of 90 degrees is attained. When the voltage is applied under this state, only the liquid crystalline molecules in the proximity of the surface of the substrate undergo twisting in such a manner as to follow the anchoring energy of the substrate surface, but twisting hardly occurs in other layers. Therefore, the mode does not substantially change to the rotatory polar-

ization mode (TN mode) but to the birefringence mode. FIG. **127** shows the change of relative luminance (transmittance) to the change of the retardation Δnd (d; μm) in both the TN mode and the birefringence mode. As shown in the graph, the birefringence mode exhibits sharper transmittance characteristics to Δnd of the liquid crystal than the TN mode. As described above, the vertical orientation liquid crystal using the n type liquid crystal executes black display when no voltage is applied and white display when the voltage is applied, by using the polarizer plate as the cross-Nicol.

FIG. **128** shows the change of the transmittance to the change of Δnd at each wavelength (R: 670 μm, G: 550 mm, B: 450 mm). It can be appreciated from this graph that when the thickness of the liquid crystal layer is set to Δnd at which luminance in white display attains the maximum, that is, to Δnd at which the transmittance attains the maximum at the wavelength of 550 nm, the transmittance at 450 nm becomes excessively low. Therefore, the thickness of the liquid crystal layer is set to a value smaller than the thickness determined from maximum luminance so as to restrict coloring in white display. Therefore, luminance in white display is lower than that of the TN mode, and in order to obtain white luminance equivalent to that of the liquid crystal display panel of the TN mode, back-light luminance must be increased. To increase this back-light luminance, however, power consumption of illumination must be increased, and the range of application of the panel is limited. When the thickness of the liquid crystal layer is increased by laying stress on white luminance, the transmittance becomes excessively low at 450 nm in comparison with the TN mode, and the panel is colored yellow in white display.

To enlarge the viewing angle range, on the other hand, it has been customary to add a phase difference film, but when the thickness of the liquid crystal layer becomes great, the color change in the direction of the critical angle (transverse direction) becomes so great that even if the retardation value of the phase difference film is the same, the color difference becomes greater.

In the 32th embodiment, the thickness of the liquid crystal layer of each color pixel is individually set so that the transmittance becomes maximal when the driving voltage is applied. However, when the thickness of the liquid crystal layer is different, a difference occurs in the response speed and the color tone cannot be displayed correctly when the operation display is carried out. Therefore, when the thickness of the liquid crystal layer is set to a different value for each color pixel, means for making uniform the response speed of the liquid crystal becomes necessary.

FIG. **129** shows the change of the liquid crystal response speed to the gap of the protrusions or the slits when Δnd of the liquid crystal layer is set so that the maximum transmittance can be obtained at the three kinds of wavelengths described above. The liquid crystal response speed becomes lower as the thickness of the liquid crystal layer becomes greater. In the VA system LCD panel which controls the orientation by using the protrusion, the liquid crystal response speed changes with the dielectric constant of the protrusion, the shape of the protrusion, the protrusion gap, and so forth. However, when the dielectric constant, the shape of the protrusion and its height are constant, the response speed becomes higher when the gap of the protrusions is narrower. It can be appreciated that to obtain the liquid crystal response speed of 25 ms, for example, in FIG. **129**, the gap of the protrusions or the slits must be set to 20 μm for the R pixel, 25 μm for the G pixel and 30 μm for the B pixel.

FIG. **130** shows the change of the aperture ratio with respect to the protrusion or slit gap. When the gap of the protrusions or the slits is set to 20 μm for the R pixel, 25 μm for the G pixel and 30 μm for the B pixel from FIG. **129** the transmittance is 80%, 83.3% and 85.7%, respectively, and the differences occur in the transmittance.

In view of this point the 32nd embodiment individually sets the thickness of the liquid crystal layer of each color pixel so that the transmittance attains the maximum when the driving voltage is applied, the response speed in each color pixel is rendered coincident by regulating the gap of the protrusions, and the area of each color pixel is changed so that the transmittance becomes coincident.

FIG. **131** shows the panel structure of the 32nd embodiment. As shown in this drawing, a structure **71** not having the R pixel portion but having the G pixel portion having a thickness of 0.55 μm and the B pixel portion having a thickness of 1.05 μm is provided to both substrates **16** and **17**. The optimum condition is calculated for this thickness by simulation for the VA system birefringence mode using the n type liquid crystal. Further, the height of the protrusion **20**A is set to 2.45 μm for the R pixel, 1.9 μm for the G pixel and 1.4 μm for the B pixel. Further, the gap of the protrusions is set to 20 μm for the R pixel, 25 μm for the G pixel and 30 μm for the B pixel. The area ratio of the B pixel:G pixel:R pixel is set to 1:1.03:1.07. In other words, the pixel areas are so set as to satisfy the relation R pixel>G pixel>B pixel.

The structure **71** uses an acrylic resin, and after a resist is applied to a thickness of 1.4 μm for the B pixel, a protrusion having a width of 5 μm is formed by photolithography. After a vertical alignment film is applied, a 3.6 μm spacer is sprayed to form a seal, and after bonding and curing of the seal, the liquid crystal is charged. In this way, the thickness of the liquid crystal layer is 5.7 μm for the R pixel, 4.6 μm for the G pixel and 3.6 μm for the B pixel.

FIG. **132** shows the panel structure of a modification of the 32th embodiment, wherein a protrusion is formed on the CF substrate **16** and a slit **21** is formed on the pixel electrode **13** of the TFT substrate **17**. In this modification, an acrylic resin structure **71** not having the R pixel portion but having the G pixel portion having a thickness of 1.1 μm and the B pixel portion having a thickness of 2.1 μm is provided to the CF substrate **16**. After a resist is applied to a thickness of 1.4 μm for the B pixel, a protrusion having a width of 5 μm is formed by photolithography. As a result, the height of the protrusion is 3.5 μm for the R pixel, 2.5 μm for the G pixel and 1.4 μm for the B pixel. The gap between the protrusion **20**A and the slit is set to 20 μm for the R pixel, 25 μm for the G pixel and 30 μm for the B pixel. The area ratio of the B pixel:G pixel:R pixel is set to 1:1.03:1.07.

A biaxial phase difference film (retardation value: 320 nm) in match with nd of the liquid crystal layer of the G pixel is added to the panels of the 32th embodiment and to its modification produced in the manner described above, and the color difference is measured for each of the panel transmittance, the viewing angle and the critical angle direction (0 to 80 degrees). The results are shown in FIG. **249**. By the way, the measurement results obtained by changing the thickness of the liquid crystal layer in the prior art example are also shown in FIG. **249** as the reference values.

As can be appreciated from FIG. **249** the transmittance (luminance) in front can be increased by increasing the thickness of the liquid crystal layer to improve the transmittance as represented by the prior art example 1, but because the length of the optical path gets elongated in the

direction of the critical angle, the transmittance of the square wavelength fluctuates greatly and the color difference becomes great. In contrast, in the panels of the 32th embodiment and its modification, the gap of the protrusions or the slits is narrowed for the R and G pixels so as to make uniform the response speed of the liquid crystal, and the transmittance becomes lower than that of the prior art example 2 as the aperture ratio is lower. Nonetheless, because the thickness of each liquid crystal layer is set so that the transmittance attains the maximum when the driving current is applied (white display), the color difference in the direction of the critical angle becomes small.

The panels according to the 32th embodiment and its modification can brighten white luminance to the level equal to the TN mode without causing coloration of the panels in the broad range of the viewing angles. Because the liquid crystal response speed is made uniform so as to correspond to the thickness of each liquid crystal layer, display can be obtained with high color reproducibility even when dynamic image display is made.

Next, processes for forming protrusions will be described.

When protrusions are formed on electrodes **12**, **13** of a CF substrate **16** and a TFT substrate **17**, the electrodes of ITO film are formed, then, a resist is coated on the surfaces and is patterned with a photolithography. This process is easily carried out by using conventional techniques.

However, this process needs a step of creating the pattern of protrusions. If protrusions can be formed on the TFT substrate by utilizing the conventional process as it is, an increase in number of steps can be avoided. For forming insulating protrusions, it is thought that an insulating layer used in the conventional process is further patterned in order to leave the pattern of protrusions intact. For creating conducting protrusions, a conductive layer used in the conventional process is further patterned in order to leave the pattern of protrusions intact

FIG. **133** is a diagram showing the structure of a TFT substrate in the 33th embodiment. The thirteenth 33th provides a structure in which an insulating layer used in the conventional process is utilized for creating insulating protrusions. In this structure, the ITO electrodes **13** are formed first. An insulating layer is formed on the ITO electrodes and portions of the insulating layer coincident with the ITO electrodes **13** are removed. At this time, portions of the insulting layer coincident with protrusions **68** are left intact. The gate electrodes **31** are then formed. An insulating layer is formed and portions of the insulating layer other than necessary portions are removed. At this time, if the protrusions are required to have a certain thickness, portions of the insulating layer coincident with the protrusions **68** are left intact. Thereafter, data bus lines and TFTs are formed in the same manner as a conventional process. In the drawing, reference numeral **41** denotes a drain (data bus line), **65** denotes a channel protective film, **66** denotes a wiring layer used to separate devices, and **67** denotes an operating layer for transistors. The ITO electrodes **13** and sources are linked by holes

FIGS. **134**A and **134**B are diagrams showing examples of a pattern of protrusions manufactured according to the process described in conjunction with the 33th embodiment. FIG. **134**A shows linear and parallel protrusions used to divide an orientation-divided domain into two regions, and FIG. **134**B shows zigzag protrusions used to divide an orientation-divided domain into four regions. In the drawings, reference numerals **68** denotes a protrusion, and **69** denotes a pixel.

FIG. **135** is a diagram showing the structure of a panel of the 34th embodiment. The 34th embodiment provides a structure in which a conductive layer used in the conventional process is utilized for forming conducting protrusions. In this structure, first, a TFT light-interceptive metallic layer **70** for intercepting light from TFTs is formed, an insulating layer is formed on the metallic layer **70**, and ITO electrodes are formed thereon. An insulating layer is formed further thereon, data bus lines and TFTs are then formed, and an insulating layer is formed further thereon. A layer of gate electrodes **31** is then formed. The insulating layer is removed except portions thereof coincident with the gate electrodes. At this time, portions of the insulating layer coincident with the protrusions **20**B are left intact

FIGS. **136**A and **136**B show examples of a pattern of protrusions manufactured as described in conjunction with the 34th embodiment. FIG. **136**A shows linear and parallel protrusions used to divide an orientation-divided domain into two regions, and FIG. **136**B shows zigzag protrusions used to divide an orientation-divided domain into four regions. In the drawings, reference numeral **20**B denotes a protrusion. Reference numeral **35** denotes a CS electrode. The CS electrodes **35** are extending along the edges of pixel electrodes so as to work as black matrices, but are separated from the protrusions **20**B. This is because the CS electrodes **35** apply a certain voltage to the pixel electrodes (ITO electrodes) **13**, and that if the voltage were applied to the protrusions **20**B, alignment of liquid crystalline molecules would be adversely affected.

FIGS. **137**A to **137**D show a process for manufacturing the TFT substrate of the panel of the 35th embodiment. As shown in FIG. **137**A, the gate electrode **31** is patterned on the glass substrate **17**. Next, the SiNx layer **40**, the amorphous silicon (α-Si) layer **72** and the SiNx layer **65** are serially formed. Further, as shown in FIG. **137**B, the SiNx layer **65** is etched to the α-Si layer **72** in such a fashion as to leave only the portion of the channel protecting film. The n+ α-Si layer and the Ti/Al/Ti layer corresponding to the data bus line, the source **41** and the drain **42** are formed, and etching is then so made by patterning as to leave only the portions corresponding to the data bus line, the source **41** and the drain **42**. After the SiNx layer corresponding to the final protecting film **43** is formed as shown in FIG. **137**D, etching is then made to the surface of the glass substrate **17** in such a manner as to leave the portions **43**B and **40**B corresponding to the portion necessary for insulation and to the protrusions. At this time, the contact hole of the source electrode **41** and the pixel electrode is formed simultaneously, too. Further, the ITO electrode layer is formed and patterned, thereby forming the pixel electrode **13**. Therefore, the height of the protrusion is the sum of the SiNx layer **40** and the final protecting film **43**.

FIG. **138** shows the structure of a modification of the panel of the 35th embodiment, and when the SiNx layer corresponding to the final protecting film **43** is etched, etching is made up to the upper surface of the SiNx layer **40**. Therefore, the height of the protrusion is the thickness of the final protecting film **43**.

FIGS. **139**A to **139**E show a process for manufacturing the TFT substrate of the panel of the 36th embodiment. As shown in FIG. **139**A, the gate electrode **31** is patterned on the glass substrate **17**. Next, the ITO electrode layer is formed and patterned to form the pixel electrode **13**. The SiNx layer **40**, the amorphous silicon (α-Si) layer **72** and the SiNx **65** are serially formed as shown in FIG. **139**B. Further, the SiNx layer **65** is etched up to the α-Si layer **72** in such a fashion as to leave only the portion of the channel

protecting film. The n^+ α-Si layer is further formed. As shown in FIG. **139**C, etching is then made up to the surface of the pixel electrode **13** in such a fashion as to leave the necessary portions and the portion **40**B corresponding to the protrusion. The Ti/Al/Ti layer corresponding to the data bus line, the source **41** and the drain **42** is formed as shown in FIG. **139**D, and is then patterned in such a fashion as to leave only the portions corresponding to the data bus line, the source **41** and the drain **42**. The n^+ α-Si layer and the α-Si **72** are etched by using the data bus line, the source **41** and the drain **42** as the mask. After the SiNx layer corresponding to the final protecting film **43** is formed as shown in FIG. **139**E, etching is made up to the surface of the pixel electrode **13** in such a fashion as to leave the portion necessary for insulation and the portions **43**B and **40**B corresponding to the protrusions.

The explanation predetermined above explains the embodiments relating to the manufacture of the protrusion **20**B on the side of the TFT substrate **17**, but there are various modifications depending on the structure of the TFT substrate **17**, and the like. In any case, the production cost can be reduced by manufacturing the protrusion by conjointly using the manufacturing process of other portions of the TFT substrate **17**.

As has been explained already, the protrusion of the dielectric material disposed on the electrode has the advantage that stable orientation can be obtained because the direction of regulation of the orientation by the slope coincides with the direction of regulation of the orientation by the electric field at the protrusion portion. However, the protrusion is the dielectric material disposed on the electrode and the alignment film is formed on the protrusion. For this reason, the inside of the liquid crystal cell becomes asymmetric between a pair of electrodes, and the charge is likely to stay with the application of the voltage. In consequence, the residual DC voltage becomes high, and the problem of so-called. "burn" occurs if the area of the projection is relatively large.

FIGS. **140**A and **140**B show the relationship between the thickness of the dielectric material on the electrode and the residual DC voltage. FIG. **140**A is a graph showing this relationship and FIG. **140**B shows the portion corresponding to the thickness d of the dielectric material and the position of the occurrence of "burn". The vertical alignment film **22**, too, is the dielectric material, and the sum of the height of the protrusion and the vertical alignment film **22** corresponds to the thickness d of the dielectric material as shown in FIG. **140**B. The residual DC voltage increases with the increase of d as shown in FIG. **140**A. Therefore, burn is likely to occur at the portion of the protrusion **20** shown in FIG. **140**B. This also holds true of the case where the dielectric depression is formed on the electrode as in the eighteenth embodiment shown in FIG. **93**. The 37th embodiment to be explained next is directed to prevent the occurrence of such a problem.

FIGS. **141**A and **141**B show the structure of the protrusion in the 37th embodiment. FIG. **141**A is a perspective view of the protrusion **20** and FIG. **141**B is a sectional view. As shown in these drawings, the protrusion **20** has a width of 7 μm, the width of its upper surface is about 5 μm and its height is about 1 to 1.5 μm. A large number of fine pores are formed on this upper surface, and each fine pore has a diameter of not greater than 2 μm.

FIGS. **142**A to **142**E are drawings showing a method of forming the protrusion (on the side of the CF substrate) having such fine pores. As shown in FIG. **142**A, the glass substrate having the opposed electrode **12** of the ITO film formed thereon is washed. A photosensitive resin (resist) is applied and is then baked to form a resist layer **351** as shown in FIG. **142**B. A mask pattern **352** permitting light to transmit through the portions other than the protrusion and the pore portions is brought into close contact with the resist layer **351** and then exposure is effected. The protrusion **20** shown in FIG. **142**D is obtained by then carrying out development. When baking is made further, the protrusion **20** undergoes shrinkage, and the side surface changes to the slope as shown in FIG. **142**E.

When the substrate having the fine pores formed in the protrusion described above and the substrate not having the pores are assembled and the residual DC voltage is measured by a flicker erasure method (DC: 3 V, AC: 2.5 V, temperature: 50 C, DC application time: 10 minutes), the residual DC voltage is 0.09 V when the fine pores are formed and is 0.25 V when they are not formed. Because the residual DC voltage is reduced in this manner, seizure becomes more difficult to occur.

The liquid crystalline molecules are oriented perpendicularly to the slopes of the protrusions, etc, and to the electric field. It has been found out, however, when the gap of the protrusions becomes smaller to the size approximate to the fine pores, the liquid crystalline molecules are not oriented to the slope of the fine portions. Therefore, the liquid crystalline molecules are affected at the upper surface portion of the protrusions by the influences of the orientation due to the slopes on both sides and are oriented along this orientation.

FIG. **143** shows the protrusion structure of the 38th embodiment. In the 3.8th embodiment, a groove having a width of 3 μm and a small thickness is disposed below the protrusion **20**B having a width of 7.5 μm on the TFT substrate side. Further, a chromic shading layer **34** is disposed below the protrusion **20**B. Such a protrusion **20**B can be manufactured by the same method as that of the 37th embodiment. When the residual DC voltage is measured for the protrusion structure of the 38th embodiment, it is 0.10V, and the result substantially equal to that of the 37th embodiment can be obtained.

In the protrusion structure of the 38th embodiment, the liquid crystalline molecules are not oriented at the groove portion in the direction perpendicular to the substrate when no voltage is applied, and the vertical orientation property gets deteriorated in some cases. However, because the shading film **34** is disposed, leaking light due to abnormal orientation at this portion is cut off and does not invite the drop of the contrast.

Next, the shape of a section of a resist was examined. Normally, the resist has a section like the one shown in FIG. **144**A immediately after completion of patterning. However, in the mode of the present invention, a cylindrical section having a rather smooth slope contributes to more stable alignment. Substrates immediately after being patterned were baked at 200° C., whereby the sectional shape of the resist was changed into the one shown in FIG. **144**B. FIGS. **145**A to **145**E are diagrams showing a change in sectional shape of the resist deriving from a change in temperature at which the patterned resist is baked. Even when the baking temperature was raised to 150° C. or more, a further change in sectional shape was limited

Talking of the reasons why the resist was baked at 200° C., aside from a reason that the sectional shape of the resist is intended to be changed, there is another important reason. That is to say, when the resist employed in the prototypes is baked normally (at 135° C. for 40 min.), it is melted while reacting upon-a solvent applied to an alignment film. In this

embodiment, the resist is baked at a high enough temperature before the alignment film is formed, and thus prevented from reacting upon the alignment film

In the first embodiment, the resist is baked at 200° C. in order to make the sectional shape of the resist cylindrical. Data that has been described so far was acquired using the pattern of protrusions whose sectional shape is cylindrical.

In the foregoing examples, the sectional shape of a resist is made cylindrical by optimizing the baking temperature. Depending on the line width of a resist, the resist becomes cylindrical naturally. FIGS. **146**A to **146**C are diagrams showing the relationships between the line width of a resist and the sectional shape thereof. When the line width is about 5 micrometers, the resist has a preferable cylindrical shape naturally. Presumably, therefore, when the line width is about 7 micrometers or less, a resist having a naturally cylindrical sectional shape can be formed. In an existing display, the line width of 5 micrometers can actually be adopted. Depending on the performance of an exposure device, even when the line width is in the unit of submicrons, the same alignment can be thought to be attained in principle.

When a protrusion is used as the domain regulating means, furthermore, it becomes necessary to form a vertical alignment film thereon. FIGS. **147**A and **147**B are sectional views of a conventional panel using protrusion as a domain regulating means, and illustrates the protrusion. Referring to FIG. **147**A, on the substrates **16** and **17** are formed color filters and bus lines as well as ITO electrodes **12** and **13**. Protrusions **20**A and **20**B are formed thereon, and vertical alignment films **22** are formed on the ITO electrodes **12** and **13** that include the protrusions **20**A and **20**B.

When the protrusion is formed by using the positive-type photoresist such as a TFT flattening agent HRC-135 manufactured by JSR Co. the surface exhibits poor wettability to the vertical alignment film, expels the material of the vertical alignment film that is applied, and makes it difficult to form a vertical alignment film on the surface of the protrusion. FIG. **147**B shows this condition. Therefore, it causes a problem in that no vertical alignment film **22** is formed on the surfaces of the protrusions **20**A and **20**B. The protrusions **20**A and **20**B having no vertical alignment film **22** formed on the surfaces thereof, do not help obtain a desired orientation. Therefore, light-leakage occurs from the protrusions to deteriorate the quality of display. A 39th embodiment is to solve this problem.

According to the 39th embodiment, the surface of the protrusion is treated so that the material of the vertical alignment film easily adheres onto the surface of the protrusion. As the treatment for enabling the material of the vertical alignment film to easily adhere to the surface of the protrusion, it can be contrived to form fine ruggedness on the surface of the protrusion so that the material of the alignment film can be favorably applied thereto, or the wettability of the surface of the protrusion can be enhanced relative to the material of the vertical alignment film. When fine ruggedness is formed on the surface of the protrusion, the liquid of the alignment film stays in the concave portions, and the material of the alignment film is less expelled by the surface of the protrusion. The ruggedness can be formed by either a chemical treatment or a physical treatment. As the chemical treatment, ashing can be effectively employed.

FIGS. **148**A to **148**C are diagrams illustrating a method of forming protrusions according to a 39th embodiment based on the ashing treatment. Referring to FIG. **148**A, a protrusion **20** is formed by using the photoresist on the electrode **13** (which, in this case, is a pixel electrode **13** but may be an opposing electrode **12**). The protrusion **20** has the shape of, for example, a stripe of a width of 10 μm and a height of 1.5 μm. The protrusion is annealed to assume the shape of a dome in cross section. The surface of protrusion on the substrate is subjected to the ashing treatment using a conventional plasma asher. Through the plasma ashing, fine dents are formed on the surface of the protrusion as shown in FIG. **148**B. The thus obtained substrate is washed, dried, and onto which a vertical orientation member is applied by using a printer. Due to the effect of ruggedness formed on the protrusion, the orientation member is not expelled, and a vertical alignment film is formed on the whole surface of the protrusion as shown in FIG. **148**C. Thereafter, the processing is executed in the same manner as that of the ordinary multi-domain VA system. The thus obtained liquid crystal display device exhibits favorable display properties without defect that stems from the expulsion of the alignment film.

Another example of the ashing treatment will be an ozone ashing treatment exhibiting the same effect as that of the plasma ashing treatment.

As a physical method of forming ruggedness, the substrate is washed with a brush by using a substrate washing machine after the protrusion has been annealed. This forms ruggedness in the form of stripes on the protrusion. Other examples of the method of physically forming ruggedness include effecting the rubbing by using a rubbing device as shown in FIG. **149**A, and transferring ruggedness of a roller **103** by pushing the rugged roller **103** onto the substrate on which the protrusion **20** has been formed as shown in FIG. **149**B.

FIG. **150** is a diagram illustrating the irradiation with ultraviolet rays in order to enhance the wettability of the surface of the protrusion relative to the material of the vertical alignment film. As described above, a protrusion **20** same as that of FIG. **148**C is formed on the substrate by using a photoresist. By using an excimer UV irradiation apparatus, the substrate is irradiated with ultraviolet rays of a main wavelength of 172 nm in an environment in which an oxygen concentration is not lower than 20% in a dosage of 1000 mJ/cm^2. This helps improve the wettability of the surfaces of the substrate and of the protrusion relative to the material of the vertical alignment film. The thus obtained substrate is washed, dried, and is coated with the vertical orientation member by using a printer. Since wettability has been improved by the irradiation with ultraviolet rays, the orientation material is not expelled, and the vertical alignment film is formed on the whole surface of the protrusion. Thereafter, the processing is carried out in the same manner as that of the ordinary multi-domain VA system. The thus obtained liquid crystal display device exhibits favorable display properties without defect that stems from the expulsion of the alignment film.

FIGS. **151**A and **151**B are graphs illustrating a change in the expulsion factor of the material of the vertical alignment: film of when the conditions are changed in which the protrusion formed of a photoresist is irradiated with ultraviolet rays. FIG. **151**A is a graph illustrating a relationship among the wavelength, dosage (radiation quantity) and expulsion factor (repellent occurrence ratio). Ultraviolet rays having a wavelength of not longer than 200 nm are effective. When the wavelength is longer than 200 nm, the improvement is accomplished to only a small degree. When the ultraviolet rays have a wavelength of not longer than 200 nm, furthermore, no expulsion (repellent) occurs with the dosage of 1000 mJ/cm^2. FIG. **151**B is a graph illustrating a relationship between the oxygen concentration and the expulsion factor of when the protrusion is irradiated with

ultraviolet rays having a wavelength of not longer than 200 mn with a dosage of 1000 mJ/cm^2. In an environment where the oxygen concentration is low, ozone is not generated in sufficient amounts and the improvement is accomplished little. It is therefore desired that the protrusion is irradiated with ultraviolet rays having a wavelength of not longer than 200 nm in an environment in which an oxygen concentration is not lower than 20% with a dosage of not smaller than 1000 mJ/cm^2.

As an apparatus for generating ultraviolet rays having a wavelength of not longer than 200 nm, there can be used a low-pressure mercury lamp in addition to the above-mentioned excimer UV irradiation apparatus.

In the above-mentioned processing, the substrate was washed and dried after irradiated with ultraviolet rays. However, the substrate may be irradiated with ultraviolet rays after it has been washed and dried. In this case, since the protrusion is irradiated with ultraviolet rays just prior to printing an alignment film thereon, wettability is not impaired by being left to stand after it is irradiated or by washing.

Repellence on the protrusion can be drastically improved if a silane coupling agent, an alignment film solvent, etc, are applied before the alignment film is applied, and then the alignment film is formed. More concretely, the substrate is baked (annealed) and the shape of the protrusion is turned into the semicylindrical shape as shown in FIG. **146**. After this substrate is washed, hexamethyldisilane (HMDS) is applied by using a spinner. A vertical orientation material is applied to the substrate by using a printing press. In this way, the vertical alignment film is satisfactorily formed on the surface of the protrusion. Incidentally, N-methylpyrrolidone (NMP) may be applied in place of HMDS. Further, printing of the vertical alignment film may be carried but in a sealed NMP atmosphere and in this case, too, the vertical alignment film can be formed satisfactorily on the surface of the protrusion. Various solvents are available as the solvent to be applied before the formation of the vertical alignment film, and gamma-butyrolactone, methyl cellosolve, etc, as the solvent of the alignment film can be used, for example.

FIGS. **152**A to **152**C are explanatory views useful for explaining an example of the production method of the protrusion in the 39th embodiment, and represents an example wherein the protrusion is formed by a material dispersing therein fine particles (particulates) (example of the CF substrate side). As shown in FIG. **152**A a positive type photosensitive resin (resist) **355** containing 5 to 20% of fine alumina particles having a grain size of not greater than 0.5 μm in mixture is applied onto the electrode **12**. The resist **355** is exposed and developed by using a photomask **356** which shades the protrusion portion, as shown in FIG. **152**B. After baking is carried out, a protrusion **20**A shown in FIG. **152**C can be obtained. The fine alumina particles **357** protrude from the surface of this protrusion **20**A and fall off from the surface to form holes. In other words, fine concave-convexities are formed on the surface of the protrusion **20**A. For this reason, wettability can be improved when the vertical alignment film is applied.

To increase the number of concave-convexities on the surface of the protrusion in the embodiment described above, the proportion of the fine alumina particles to be mixed with the resist must be increased. When the proportion of the fine alumina particles exceeds 20%, however, the photosensitivity of the resist drops and patterning can not be carried out by exposure. FIGS. **153**A to **153**C show a method

of manufacturing the protrusion when the number of the concave-convexities on the surface of the protrusion must be increased.

A non-photosensitive resin containing a great proportion of fine alumina particles **357** having a grain size of not greater than 0.5 μm is applied onto the electrode **12** as shown in FIG. **153**A. Further, as shown in FIG. **153**B, a resist is applied to the surface of the resin, and exposure and development are carried out by using a photomask **358** shading the protrusion portion. Because the resist remains at only the portions corresponding to the photomask **358**, the non-photosensitive resin at portions other than the protrusion portion is removed by etching. When baking is carried out further, the protrusion **20**A can be obtained as shown in FIG. **153**C. The concave-convexities are formed similarly on the surface of the protrusion **20**A but because the proportion of the fine alumina particles **357** mixed is great, a large number of concave-convexities are formed, and wettability can be much more improved than in the embodiment shown in FIG. **154** when the vertical alignment film is applied.

FIGS. **154**A and **154**B show another manufacturing method of the concave-convexities on the surface of the protrusion by the fine particles. In this example, after the resist **360** is applied to the surface of the electrode **12**, the fine alumina particles **361** are sprayed and allowed to adhere to the surface of the resist **360**, followed then by pre-baking. Thereafter, the protrusion is patterned in the same way as in the prior art, and the protrusion **20**A shown in FIG. **154**B can be obtained. When this protrusion **20**A is washed, the fine alumina particles **361** exist on the surface of the protrusion **20**A and fall off from the surface to define the holes. In consequence, the concave-convexities are formed.

FIGS. **155**A and **155**B are explanatory views useful for explaining an example of the manufacturing method of the protrusion in the 39th embodiment, and represents the example wherein a protrusion material is foamed to form the concave-convexities on the surface of the protrusion. The resist for forming the protrusion **20** is first dissolved in a solvent such as PGMEA (Propylene-Glycol MonoMethyl Ether Acetate), for example, is applied by a spinner and is then pre-baked (pre-cured) at 60° C. Under this state, large quantities of the solvent remain inside the resist. Patterning is then carried out by exposure and development by using a mask.

According to the embodiments as described above, as shown in FIG. **156** with a broken line, the temperature is gradually raised inside a clean oven up to 200° C. in the course of 10 minutes, is held at this temperature for longer than 75 minutes and is gradually returned to the normal temperature in the course of 10 minutes. In contrast, according to this embodiment, as shown in FIG. **156** with a continuous line, the substrate is placed on a hot plate at 200° C. and is heated for 10 minutes. At this time, about one minute time is necessary to raise the substrate temperature to 200° C. Thereafter, the substrate is left standing for cooling for 10 minutes to the normal temperature. When quick heating is carried out in this way, the solvent inside the resist is bumped and bubbles **362** are formed inside the resist as shown in FIG. **155**A. The bubbles **362** are emitted outside from the surface of the protrusion **20** as shown in FIG. **155**B. At this time, the traces **363** of the bubbles are left on the surface of the protrusion, forming thereby the concave-convexities.

Incidentally, when the resist dissolved in the solvent is stirred before the application and the bubbles are introduced into the resist, foaming is more likely to occur than when the resist is quickly heated. Stirring may be carried out while a

nitrogen gas or a carbonic acid gas is being introduced. According to this method, the bubbles of the gas are introduced into the resist and a part of the gas is dissolved in the solvent, so that formability at the time of heating increases. Water of crystallization which emits water at about 120 to about 200° C. or a clathrate compound which emits a guest solvent may be mixed with the resist, too. Water is emitted from water of crystallization and changes to a steam or the guest solvent is emitted at the time of heating, and foaming is more likely to occur. A solvent or a silica gel adsorbing a gas may be mixed with the resist. The adsorbed solvent or the gas is emitted from the silica gel at the time of heating and consequently, foaming is more likely to occur. Incidentally, the solid material to be mixed must be smaller than the height of the protrusion and its width, and must be pulverized in advance to such a size.

The fine pores are formed in the protrusion in the 37th embodiment whereas the grooves are disposed in the protrusion in the 38th embodiment, and according to such structures, the vertical alignment film can be formed more easily on the surface of the protrusion. FIGS. **157**A to **157**C show another method of forming the protrusion having the grooves such as those of the 38th embodiment.

As shown in FIG. **157**A, the protrusions **365** and **366** are formed adjacent to one another by using a photoresist which is used for forming a micro-lens. The patterning shape of this micro-lens can be changed depending on the light reflection intensity, the baking temperature, the composition, and so forth, and when the suitable baking condition is set, the protrusion collapses and changes to the shape shown FIG. **157**B. When the vertical alignment film **22** is applied to this shape, as shown in FIG. **157**C, the vertical alignment film **22** can be formed satisfactorily because the center of the protrusion **20** is recessed. After the material described above is applied to a thickness of 1.5 μm, the protrusions **365** and **266** are patterned to a width of 3 μm and a gap of 1 μm between the protrusions. The film is then baked at 180° C. for 10 to 30 minutes. As a result, two protrusions are fused to each other to form the shape shown in FIG. **157**B. A desired shape can be obtained by controlling the baking time. The protrusions **365** and **266** can be fused to one another when the height is from 0.5 to 5 μm, the width is from 2 to 10 μm and the gap is within the range of 0.5 to 5 μm. When the height of the protrusions is greater than 5 μm, this height affects the cell thickness (thickness of the liquid crystal layer) and impedes injection of the liquid crystal. When the width of the protrusion is smaller than 2 μm, on the other hand, the orientation limiting force of the protrusion drops. Furthermore, when the gap between the protrusions exceeds 5 μm, the two protrusions cannot be fused easily and when it is smaller than 0.5 μm, the depression can not be formed at the center.

In the foregoing was described the treatment for improving wattability of the protrusion relative to the material of the alignment film according to the 39th embodiment. Here, the protrusion may have any pattern and may not be of the shape of a dome in cross section. Moreover, the material forming the protrusion is not limited to the photoresist but may be of any material provided it is capable of forming a protrusion in a desired shape. By taking into consideration the chemical or physical formation of ruggedness in a subsequent process, however, it is desired to use a material which is soft, is not easily peeled off and can be subjected to the ashing. The materials satisfying these conditions will be photoresist, black matrix resin, colored filter resin, overcoating resin and polyimide resin. These organic materials make it possible to improve (treat) the surfaces through the ashing or UV irradiation.

According to the 39th embodiment as described above, wettability of the surface of the protrusion is improved for the material of the alignment film, making it possible to prevent a trouble in that the alignment film is not formed on the surface of the protrusion, the quality of display is improved and the yield is improved.

In the past, a so-called black matrix is placed on the perimeter of each pixel in order to prevent deterioration of contrast deriving from leakage of light passing through a region between pixels. FIG. **158** is a diagram showing the structure of a panel of a prior art provided with black matrices. As illustrated, a red filter **39**R, green filter **39**G, and blue filter **39**B that coincide with red, green, and blue pixels are formed on a color filter (CF) substrate **16**, and ITO electrodes **12** are formed on the CF substrate. Furthermore, black matrices **34** are formed on the borders among the red, green, and blue pixels. Data bus lines and gate bus lines or TFT devices **33** are formed together with ITO electrodes **13** on a TFT substrate **17**. A liquid-crystal layer **3** is interposed between the two substrates **16** and **17**.

FIG. **159** is a diagram showing the structure of a panel of the 40th embodiment of the present invention, and FIG. **160** is a diagram showing a pattern of protrusions over pixels in the 40th embodiment. As illustrated, the red filter **39**R, green filter **39**G, and blue filter **39**B are formed on the CF substrate **16**. As shown in FIG. **160**, the protrusions **20**A for controlling alignment, which are included in the liquid crystal panel of the first embodiment, are formed on the CF substrate **16**, though they are not shown in FIG. **159**. The protrusions **20**A are made of a light-interceptive material. Protrusions **61** are formed on the perimeters of pixels. The protrusions **61** are also made of a light-interceptive material and function as black matrices. The necessity of forming the black matrices **34** like in the prior art is obviated. The protrusions **61** functioning as black matrices can be formed concurrently with the protrusions **20**A. Using this process of manufacturing, the step of creating black matrices in the course of creating the CF substrate **16** can be omitted. Reference numeral **62** denotes a TFT in each pixel. The protrusions **61** are designed to intercept light from the TFTs.

In FIG. **159**, the protrusions **20**A and **61** are formed on the CF substrate **16**. Alternatively, the protrusions **61** or **20**A or both of them may be formed on the TFT substrate **17**. Owing to this structure, a mismatch between the CF substrate **16** and TFT substrate **17** occurring during bonding need not be taken into account. Consequently, the numerical aperture of the panel and the yield of a bonding step can be improved outstandingly. Assuming that the CF substrate **16** is provided with black matrices, when the ITO electrodes **13** on the TFT substrate **17** and open portions (portions without the black matrices) of the CF substrate **16** are designed to be mutually identical, if a bonding mismatch occurred in the process of manufacturing the panel, the mismatch region would cause light leakage. This disables normal display. Generally, even if a high-precision bonding machine is employed, a matching error of about ±5 micrometers (μm) is present. A corresponding margin must therefore be preserved. In consideration of the margin, an aperture for each black matrix is designed to be smaller. Thus, the above problem is coped with. That is to say, each black matrix is designed to invade into an ITO electrode **13** formed on the TFT substrate **17** by about 5 to 10 micrometers. When the protrusions **61** are formed on the TFT substrate **17**, the panel is free from the adverse effect of the bonding mismatch. Consequently, the

numerical aperture can be maximized. This advantage becomes greater as each pixel of the panel gets smaller, that is, as a resolution improves. For example, in this embodiment, a substrate having ITO electrodes of pixels of which width is 80 micrometers and height is 240 micrometers is employed. In any of the conventional modes, since a margin of 5 micrometers is needed, the width and length of the aperture become 70 micrometers and 230 micrometers respectively, and the area of an aperture for each pixel becomes 16100 square micrometers. By contrast, in this embodiment, the area of the aperture for each pixel is 19200 square micrometers. The numerical aperture is improved to be approximately 1.2 times larger than the one permitted by the conventional mode. For realizing a display that offers twice as high a resolution as the one provided by the panel, the width and length of an electrode are 40 micrometers and 120 micrometers respectively. In the conventional mode, the area of the aperture for each pixel is 3300 square micrometers. In this embodiment, the area of the aperture for each pixel is 4800 square micrometers and thus improved to be approximately 1.5 times higher than the one permitted by the conventional mode. Thus, the higher the resolution is, the greater the advantage is.

FIG. **161** is a diagram showing a pattern of a black matrix (BM) according to a 41th embodiment. It was described above that light leaks at the domain regulating means. A minute domain having an orientation angle 90° different located at about the top of the protrusion can be used as described above. The light leaks, however, unless a stable orientation can be secured at about the top of the protrusion. For the contrast to be improved, therefore, the domain regulating means is preferably masked. One method of masking the protrusion is to form the protrusion of a light-shielding material. According to the 41th embodiment, however, the domain regulating means is masked by use of a black matrix (BM).

As described above, the BM **34** is used for shielding the leakage light at the TFT and the boundary between the cell electrode and the bus line. The 41th embodiment, however, uses the BM also at the domain regulating means. Consequently, the leakage light at the domain regulating means can be masked for an improved contrast.

FIG. **162** is a sectional view of a panel according to a 41st embodiment. As shown, the BMs **34** are arranged at positions corresponding to the protrusions **20**A, **20**B, the TFT **33**, and the interval between the bus lines (only the gate bus line **31** is shown) and the cell electrodes **13**.

FIG. **163** shows a pixel pattern according to a 42nd embodiment. Conventionally, a delta arrangement is known, in which the display pixels, which are substantially square in shape, are arranged in adjacent columns one half of a pitch displaced from each other. In a color liquid crystal display device, a set of color pixels is configured of three adjacent pixels of **13**B, **13**G, **13**R. Each pixel is almost square in shape, and as compared with a 1-to-3 rectangle, an equal proportion of liquid crystalline molecules can be easily secured in each direction of division without reducing the protrusion interval considerably. In such a case, the data bus line is extended in zigzag along the perimetric edge of the pixel. In this way, the delta arrangement is very effective in the case where a protrusion arrangement or a depression arrangement is continuously formed over the entire substrate surface for orientation division.

The 43rd embodiment to be described next is an embodiment using the protrusions for controlling alignment or the protrusions **61** serving as black matrices in the 40th embodiment as spacers. As also shown in FIG. **19**, spacers are used to retain the distance (gap) between two substrates (thickness of cells) at a predetermined value. FIG. **164** is a diagram showing the structure of a panel of a prior art, wherein spacers **45** are placed on borders between pixels and define the thickness of cells. The spacers **45** are, for example, spheres having a predetermined diameter.

FIGS. **165**A and **165**B are diagrams showing the structure of a panel of the 43rd embodiment. FIG. **165**A shows the structure of the panel of the 43rd embodiment, and FIG. **165**B shows a modification. As shown in FIG. **165**A, in the panel of the 43rd embodiment, protrusions **64** formed on the perimeters of pixels are made as thick as cells, and thus define the thickness of cells. In the drawing, the protrusions **64** are formed on the TFT substrate **17**. Alternatively, the protrusions **64** may be formed on the CF substrate **16**. This structure obviates the necessity of including spacers. No liquid crystal is present at the positions of the protrusions **64**. For a vertically-aligned panel or the like, the positions of protrusions (cell holder areas) of the panel appear in black all the time irrespective of an applied voltage. The black matrices are therefore unnecessary, and the protrusions **64** need not be made of a light-interceptive material but can be made of a transparent material.

In the 43rd embodiment shown in FIG. **165**A, the protrusions **64** define the thickness of cells. The precision in thickness of cells is dominated by the precision in forming the protrusions, and is therefore poorer than that permitted when the spacers are used. A panel having the structure of the sixteenth embodiment was actually produced. As a result, a level of uncertainty in thickness of cells can be controlled within ±0.1 micrometers. This level would not pose any particular problem in practice. However, this structure is unsuitable when the thickness of cells must be controlled strictly. The modification shown in FIG. **167**B is a structure intended to solve this problem. In the modification shown in FIG. **167**B, the spacers **45** are mixed in a resin to be made into the protrusions **65**, and the resin is applied to the substrate. The substrate is then patterned in order to form the protrusions. In this modification, the merit of the 43rd embodiment that the spacers are unnecessary is lost, but there is a merit that the thickness of cells can be defined irrespective to the precision in drawing a pattern of protrusions. A panel having the structure shown in FIG. **167**B was produced actually. The thickness of cells could be defined so precisely that an error falls within ±0.05 micrometers. Nevertheless, the spacers are still needed. However, since the spacers are mixed in a resin, the spacers are arranged while the resin is being applied. This obviates the necessity of scattering the spacers at a panel production step. The number of steps included in the process does not increase.

FIGS. **166**A and **166**B are diagrams showing another modifications of the 43rd embodiment. FIG. **166**A shows a structure in which the protrusions **64** of the 43rd embodiment are replaced with protrusions **81** made of a light-interceptive material, and FIG. **166**B shows a structure in which the protrusions **65** shown in FIG. **165**B are replaced with protrusions **82** made of a light-interceptive material. As mentioned above, in FIGS. **165**A and **165**B, the protrusions **64** and **65** may be made of a transparent material. The protrusions can still fill the role of black matrices. However, when the protrusions are made of the light-interceptive material, perfect light interception can be achieved.

FIG. **167** is a diagram showing a modification of the 43rd embodiment. Protrusions **83** are formed on the CF substrate **16** and protrusions **84** are formed on the TFT substrate **17**. The protrusions **83** and **84** are brought into contact with each

other, thus defining the thickness of cells. An effect exerted is the same as the one exerted by the 43rd embodiment and its modification.

In the 43rd embodiment and its modification, protrusions lying on the perimeters of pixels are used to define the thickness of cells. Protrusions for controlling alignment, for example, the protrusions **20**A shown in FIG. **160** may be used to define the thickness of cells.

Furthermore, in the 40th embodiment, 43rd embodiment, and modifications of the 43rd embodiment, protrusions are formed all over the perimeters of pixels. Alternatively, the protrusions may be formed on parts of the perimeters of the pixels. For example, the protrusions **61**, **64** and **81** to **84** in the 43rd embodiment and its modification may be made of a light-interceptive material and formed along one sides of only TFT portions of pixels, that is, portions **62** shown in FIG. **59**. As mentioned above, as far as a so-called normally black-mode panel that, like a vertically-aligned (VA) panel, appears in black when no voltage is applied to ITO electrodes is concerned, even if the black matrices are excluded, light leakage hardly poses a problem. In this embodiment, therefore, only the TFT portions of pixels are coated with a light-interceptive resin but the drain bus lines and gate bus lines surrounding the pixels are not coated therewith. As mentioned above, as the number of light-interceptive regions decreases, the numerical aperture improves accordingly. This is advantageous. The structure in which protrusions are formed along only the TFT portions can be adapted to the 43rd embodiment and its modifications shown in FIGS. **165**A to **169**.

In the 43rd embodiment, the black matrix is provided with the function of the spacer but according to the prior art, spherical spacers having a diameter equal to the cell thickness are sprayed on one of the substrates having the vertical alignment film formed thereon and then the other substrate is bonded. When the protrusion is formed on the electrode, however, a part of the spacers so sprayed is positioned on the protrusion if the diameter of the spacers is equal to the cell thickness in the case where no protrusion is formed, the cell thickness becomes greater than the desired thickness due to the existence of the spacer on the protrusion. Further when any force is applied from outside to the panel that is once assembled and the spacers move on the protrusion, the cell thickness becomes greater at that portion and the problem of non-uniform display develops. The forty-fourth embodiment to be next explained is directed to solve this problem by decreasing the diameter of the spacers in consideration of the thickness of the protrusion.

FIGS. **168**A to **168**C show the panel structure of the 44th embodiment. FIG. **168**A shows the TFT substrate **17** before assembly, FIG. **168**B shows the CF substrate **16** before assembly and FIG. **168**C shows the assembled state. As shown in FIGS. **168**A and **168**B, the protrusion **20**A is formed on the electrode **12** of the CF substrate **16** and the vertical alignment film **22** is further formed. The protrusion **20**B is formed on the electrode **13** of the TFT substrate **17** and the vertical alignment film **22** is before assembly and further formed. The protrusions **20**A and **20**B have the same height of 1 μm and are assembled so that they do not cross mutually when viewed from the panel surface. The cell thickness is 4 micrometers (μm), and the diameter of the spacer **85** made of a plastic material is 3 μm which is the balance obtained by subtracting the height of the protrusion from the cell **163** A thickness. As shown in FIG. **168**A, 150 to 300 pcs/mm^2 of spacers **85** are sprayed (sprinkled) on the TFT substrate **17**. A seal is formed from a bonding resin on the CF substrate **16** and the CF substrate **16** is bonded to the

TFT-substrate **17**. The spacers **85** are positioned on the protrusions **20**B or below the protrusions **20**A at a certain probability as shown in FIG. **168**C. This probability corresponds to the proportion of the areas of the protrusions **20**A and **20**B to the entire area. Under the state shown in FIG. **168**C, the cell thickness is limited by the spacers positioned on the protrusions **20**B or below the protrusions A and the thickness of the protrusions. The spacers **45** existing at portions other than the protrusions **20**A and **20**B are floating spacers that do not affect the cell thickness. Since the cell thickness is limited by the protrusions **20**A and **20**B, the cell thickness hardly exceeds the desired value. Even when the spacers at portions other than the portions of the protrusions move to the protrusion portions during the use of the panel, the cell thickness does not become thick, and even when the spacers existing at the protrusion portions move to the portions other than the protrusion portions, they change to only the floating spacers.

FIG. **169** is a graph showing the relationship between the scattered (sprinkle) density of the spacers and the cell thickness. When the scattered density of the spacers is 100 to 500 pcs/mm^2 the cell thickness falls within the range of 4 μm±0.5 μm.

Next, FIG. **172** shows the experimental result of variance of the cell thickness that occurs when a force is applied from outside to the panel, and the scattered density of the spacers. It can be appreciated from this result that when the scattered density is lower than 150 pcs/mm^2, variance is likely to occur again t the force applied, and when the scattered density exceeds 300 pcs/mm^2, variance is likely to occur against the tensile force. Therefore, the optimum scattered density is 150 to 300 pcs/mm^2.

In the manufacturing process of the liquid crystal display panel, ionic impurities are sometimes entrapped and ions contained in the liquid crystal and ions eluting from the alignment film, the protrusion forming material, the seal material, etc, mix in the liquid crystal panel in some cases. When the ions mix into the liquid crystal panel, the specific resistance of the panel drops, so that the effective voltage applied to the panel drops, too, thereby resulting in burn of the display and in the drop of the voltage retention ratio. In this way, mixing of the ions into the panel lowers display performance and reliability of the liquid crystal panel.

For these reasons, the ion adsorption capacity is preferably provided to the dielectric protrusion formed on the electrode, used as the domain regulating means in the embodiments described above. There are two methods of providing the ion adsorption capacity to the protrusion. The first method irradiates the ultra-violet rays and the second adds a material having the ion adsorption capacity to the material of the protrusion.

Surface energy of the protrusion forming material rises when the ultra-violet rays are irradiated to the material. Consequently, the ion adsorption capacity can be improved. The surface energy γ can be expressed by the sum of the polarity term γp of the surface energy and its scatter term γd. The polarity term is based on the Coulomb electrostatic force and the scatter term, on the scatter force among the van der Waals force. When the ultra-violet rays are irradiated, bonding at portions having a low bonding energy is cut off, and oxygen in air combines with the cut portions. Accordingly, the polarizability of the surface increases, the polarity term becomes great and the surface energy increases. When the degree of polarization increases, the ions become more likely to be adsorbed to the surface. In other words, the surface of the protrusion comes to possess the ion adsorption capacity when the ultra-violet rays are irradiated. It is

preferred to selectively irradiate the ultra-violet rays to only the protrusions when irradiating the ultra-violet rays, but because the bonds of the protrusion forming material are more likely to be cut off than the bonds on the surface of the substrates, only the protrusions come to possess the ion adsorption capacity even when the ultra-violet rays are irradiated to the entire surface of the panel. The vertical alignment film is formed after the ultra-violet rays are irradiated.

An ion exchange resin, a chelating agent, a silane coupling agent, a silica gel, alumina, zeolite, etc, are known as the materials having the ion adsorption capacity. Among them, the ion exchange resin exchanges the ions, and supplements the ions that have existed as impurities from the beginning. Instead, it discharges other ions and for these reasons, it is not suitable for the protrusion forming material. Among the materials having the ion supplementing capacity, some materials exist which have the ion supplementing capacity without emitting the substituent ions, and such materials are preferably used. Examples of such materials are crown ether having the chemical formula shown in FIGS. **171**A and **171**B and kryptand having the chemical formula shown in. FIGS. **172**A and **172**B. Further, inorganic materials such as alumina and zeolite have the capacity of supplementing ions without emitting ions. Therefore, these materials are used. Incidentally, since the kinds of the ions adsorbed by one ion adsorption material are limited, materials adsorbing different ions are preferably used in combination.

A protrusion line having a width of 7.5 μm, a height of 1.5 μm and a gap of 15 μm between the protrusions is formed from a positive type resist, and is subjected to the treatment for imparting the various ion adsorption capacity described above so as to manufacture the panels.

FIG. **250** shows the result of measurement of the initial ion density and the ion density (unit: pc) after the use for 200 hours of the panel so manufactured. In FIG. **250**, ultra-violet rays of 1,500 mJ are irradiated in Example C, 0.5 wt % of crown ether is added in Example D, zeolite is added in Example E, and crown ether and zeolite are added in Example F. For reference, the case where the treatment for imparting the ion adsorption capacity is not carried out is represented as Comparative Example. A 10 V triangular wave having a frequency of 0.1 Hz is applied at the time of use, and the temperature at the time of measurement is 50° C. It can be appreciated from the result that the initial value of the ion density remains at substantially the same level regardless of the ion adsorption capacity treatment. However, the ion density after 200 hours drastically increases when this treatment is not carried out, but when the treatment is carried out, the increase remains small.

When the sample to which the ultra-violet rays are irradiated and the sample which is not at all treated are subjected to the practical running test, burn occurs in the un-treated sample but does not occur in the sample subjected to the ultra-violet irradiation.

In the 40th embodiment, the structure in which a pattern of protrusions is drawn on the CF substrate **16** using black matrices has been disclosed. The structure will be described below.

As mentioned above, if a pattern of protrusions can be drawn on the CF substrate **16** in the conventional manufacturing process, since a new step need not be added, an increase in cost deriving from drawing of a pattern of protrusion can be minimized. The seventeenth embodiment is an embodiment in which a pattern of protrusions are drawn on the CF substrate **16** by utilizing the conventional manufacturing process.

FIGS. **173**A and **173**B are diagrams showing the structure of the CF substrate of the 45th embodiment. As shown in FIG. **173**A, in the 45th embodiment, the color filter (CF) resins **39**R and **39**G (and **39**B) are applied pixel by pixel to the CF substrate **16**. Black matrices or an appropriate material such as a CF resin or any other flattening resin is used to define a pattern of protrusions **50**A by tracing predetermined positions. ITO (transparent) electrodes **12** are then formed on the pattern of protrusions. A material to be made into the black matrices is not restricted to any specific one. For forming protrusions, however, a certain thickness is needed. From this viewpoint, the adoption of a resin is preferable.

FIG. **173**B is a diagram showing a modification of the CF substrate in the 45th embodiment. Black matrices or an appropriate material such as a CF resin or any other flattening resin is used to draw a pattern of protrusions **50**B by tracing predetermined positions on the CF substrate **16**. Thereafter, the CF resins **39**R and **39**G are applied. Consequently, the CF resin defining the pattern of protrusions gets thicker. The pattern of protrusions can now provide protrusions as it is. The ITO (transparent) electrodes **12** are then formed.

According to the structure of the 45th embodiment, protrusions can be formed at any positions on the CF substrate.

FIG. **174** is a diagram showing the structure of a panel of the 46th embodiment. In the 46th embodiment, the protrusions **50** are formed on the perimeters of pixels on the CF substrate **16**, that is, on seams between the CF resins **39**R, **39**G, and **39**B or on seams relative to black matrices **34**. On the TFT substrate **17**, the protrusions **20**B are formed at positions coincident with intermediate positions between the seams. For forming continuous protrusions along one sides of the pixels opposed to the seams on the CF substrate **16**, that is, for drawing a pattern of linear protrusions, a pattern of linear protrusions is drawn parallel to the pattern of protrusions by tracing positions near the centers of the pixels on the TFT substrate. Moreover, when continuous protrusions are formed along all sides of the seams between the pixels on the CF substrate **16**, the pattern shown in FIGS. **80**A to **81** is drawn. On the TFT substrate **17**, pyramidal protrusions are formed near the centers of the pixels.

The structure of the panel of the 46th embodiment can be adapted to various forms. An example of the structure of the CF substrate of the 46th embodiment will be described below.

FIGS. **175**A to **180**B are diagrams showing examples of the structure of the CF substrate of the 46th embodiment. FIG. **175**A shows a structure in which the black matrix (BM) **34** is interposed between each pair of the CF resins **39**R and **39**G. The black matrices **34** are formed thicker than the CF resins, and the ITO electrodes **12** are formed on the black matrices **34**. The black matrices **34** become protrusions. Even in this case, the black matrices **34** should preferably be made of a resin or the like.

In FIG. **175**B, the thin black matrices **34** made of a metal or the like are formed on the CF substrate **12**. The CF resins **39**R and **39**G are applied to the black matrices, thus forming color filters. Thereafter, the CF-resin **39** is applied in order to form protrusions **70**. The ITO electrodes **12** are formed on the protrusions.

In FIG. **176**A, the thin black matrices made of a metal or the like are formed on the CF substrate **12**. The CF resins **39**R and **39**G are applied to the substrate, thus forming color

filters. A resin other than the CF resin, for example, a resin used as a flattening material is used to form protrusions **71** without the use of the black matrices **34**. The ITO electrodes **12** are then formed on the protrusions. In this case, like the structure shown in FIG. **175**A, the flattening material is applied thicker than the CF resin.

In FIG. **176**B, a resin or the like is used to form the black matrices **34**, of which thickness is the same as the thickness of protrusions, on the CF substrate **12**. The CF resins **39**R and **39**G are applied so that they will overlap the black matrices **34**, thus forming color filters. Thereafter, the ITO electrodes **12** are formed. The portions of the CF resins overlapping the black matrices **34** serve as protrusions.

In FIG. **177**A, the thin black matrices **34** made of a metal or the like are formed on the CF substrate **12**, and the CF resin **39**R is then applied to the substrate. Thereafter, the CF resin **39**G is applied to overlap the CF resin **39**R, and the ITO electrodes **12** are then formed. Portions of the CF resin **39**G overlapping the CF resin **39**R serve as protrusions. At the positions of the protrusions, the black matrices **34** are included for not allowing passage of light. Either of the color filter resins may overlap the other color filter resin. According to this structure, protrusions can be formed at the step of forming color filters. The number of steps will therefore not increase.

In FIG. **177**B, a flattening material **71** is applied to overlap parts of the CF resins **39**R and **39**G on the same substrate as the one shown in FIG. **176**A. Portions of the flattening material **71** overlapping the CF resins serve as protrusions. Owing to this structure, the flattening material **71** can be made as thin as the height of protrusions.

The aforesaid structures are structures in which ITO electrodes are formed on protrusions and electrodes have the protrusions. Next, an example of a structure in which an insulating material is used to form protrusions on the ITO electrodes will be described.

In FIG. **178**, after color filters are formed on the CF substrate **16** by applying the CF resins **39**R and **39**G, the ITO electrodes **12** are formed. The black matrices **34** are then placed in order to form protrusions. Even in this case, the number of steps will not increase.

In FIG. **179**A, after the thin black matrices **34** are formed on the CF substrate **16**, the ITO electrodes **12** are formed. Color filters are then formed by applying the CF resins **39**R and **39**G. At this time, the CF resin **39**G is applied to overlap the CF resin **39**R, thus forming protrusions. Even in this case, the number of steps will not increase.

In FIG. **179**B, after the thin black matrices **34** are formed on the CF substrate **16**, color filters are formed by applying the CF resins **39**R and **39**G. The ITO electrodes **12** are then formed. The flattening material **71** is then used to form protrusions.

In FIG. **180**A, after the ITO electrodes **12** are formed on the CF substrate **16**, color filters are formed by applying the CF resins **39**R and **39**G. The black matrices **34** are then placed on the color filters, thus forming protrusions.

In FIG. **180**B, after the thin black matrices **34** are formed on the CF substrate **16**, color filters are formed by applying the CF resins **39**R and **39**G. A flattening material **72** is used to flatten the surface. The ITO electrodes **12** are then formed on the surface and the black matrices **34** are further formed, whereby protrusions are realized.

FIGS. **181**A to **181**G are diagrams illustrating the steps for producing the color filter (CF) substrate according to a 47th embodiment. The CF substrate has a protrusion as a domain regulating means.

Referring to FIG. **181**A, a glass substrate **16** is prepared. Then, as shown in FIG. **181**B, a resin (resin B, CB-7001, manufactured by Fuji Hanto Co.) **39**B' for negative-type flue filter is applied onto the glass substrate **16** maintaining a thickness of 1.3 μm. Then, as shown in FIG. **181**C, the resin B is formed on the portions of the blue (B) pixel, BM portion and protrusion **20**A by the photolithography method using a photomask **370** as shown. Next, referring to FIG. **181**D, a resin (resin R, CR-7001, manufactured by Fuji Hanto Co.) **39**R' for red filter is applied to form the resin R on the portions of the red (R) pixel, BM portion and protrusion **20**A by the photolithography method. Referring to FIG. **181**E, a resin (resin G, CG-7001, manufactured by Fuji Hanto Co.) **39**G' for green filter is applied to form the resin G on the portions of the green (G) pixel, BM portion and protrusion **20**A by the photolithography method. Through the above-mentioned steps, corresponding color filter (CF) layers are formed in one layer only on the pixel portions B, G and R, and the resins B, G and R are formed in three layers being superposed one upon the other on the BM portion and on the protrusion **20**A. The portions where the resins B, G and R are superposed in three layers are black portions without almost permitting the passage of light.

Next, a transparent flattening resin (HP-1009 manufactured by Hitachi Kasei Co.) is applied by a spin coater maintaining a thickness of about 1.5 μm, post-baked in an oven heated at 230° C. for one hour, and an ITO film is formed by mask-sputtering. Referring next to FIG. **181**F, a black positive-type resist (CFPR-BKP manufactured by Tokyo Ohka Co.) is applied by the spin coater maintaining a thickness of about 1.0 to −1.5μ, pre-baked, and is exposed to ultraviolet rays having a wavelength of 365 nm in a dosage of 1000 mJ/cm^2 from the back surface of the glass substrate **16** through the CF resin. The portions where the resins B, G and R are superposed in three layers permit ultraviolet rays to transmit through less than through other portions, and where a threshold value of exposure is not reached. When developed with an alkali developing solution, the BM portion **34** and the protrusion **20**A are formed that were not exposed to light, and are post-baked in an oven heated at 230° C. for one hour. Moreover, a vertical alignment film **22** is formed to complete the CF substrate.

FIG. **182** is a sectional view of a liquid crystal panel completed by sticking the CF substrate **16** prepared as described above and a TFT substrate **17** together. In the TFT substrate **17**, a slit **21** is formed as a domain regulating means in the pixel electrode **13**, and a vertical alignment film **22** is formed thereon. Reference numeral **40** denotes a gate protection film and a channel protection film. On the portions where the light must be shielded, the BM **34** and the resins of the three layers B, G and R are superposed one upon the other to favorably shield the light . . . . The protrusion **20**A of the CF substrate **16** and the slit **21** in the TFT substrate **17** divide the orientation of liquid crystals making it possible to obtain good viewing angle characteristics and high operation speed.

According to the 47th embodiment as described above, the protrusion **20**A which is the domain regulating means and the BM **34** are formed on the CF substrate without the need of exposure to light through a pattern, but by patterning by exposure to light from the back surface, making it possible to simplify the steps for forming the protrusion **20**A and the BM **34**, to lower the cost and to increase the yield.

In the 47th embodiment, the pigment scatter method is employed for forming the CF. This can be similarly adapted even to the dying method and to the case where a non-photosensitive resist formed by dispersing a pigment in the

polyimide is to be formed by etching. According to the 47th embodiment, the CF resins are superposed in three layers on the portions of the protrusion **20**A and BM **34**. These resins, however, may be superposed in two layers provided the wavelength of the irradiation light and the irradiation energy are suitably selected at the time of exposure through the back surface.

In the 47th embodiment, the BM and the protrusion which is the domain regulating means are formed on the CF substrate without patterning. However, the fifth embodiment can be also adapted even to the case where the BM only is formed without forming protrusion, as a matter of course. A 48th embodiment deals with a case where the BM is formed but forming the protrusion by a method different from that of the 47th embodiment.

FIGS. **183**A and **183**B are diagrams illustrating a step of producing the CF substrate according to the 48th embodiment, and FIGS. **184**A and **184**B are diagrams illustrating a panel structure according to the 48th embodiment.

In the 48th embodiment, no CF resin is superposed on a portion corresponding to the protrusion but the CF resin is superposed on a portion corresponding to the BM only to form a BM protrusion **381**. Next, without effecting the flattening, an ITO film **12** is formed as shown in FIG. **183**A, and the above-mentioned black positive-type resist **380** is applied thereon maintaining a predetermined thickness, for example, about 2.0 μm to 2.5 μm. Then, the developing is effected by exposure to light from the back surface to obtain a panel having a BM resist **380** superposed on the BM protrusion **381** as shown in FIG. **183**B. The BM **34** is constituted by both the BM protrusion **381** and the BM resist **380**.

The CF substrate and the TFT substrate are stuck together to prepare a panel shown in FIG. **184**A. FIG. **184**B is a view illustrating, on an enlarged scale. A circular portion of a dotted line of FIG. **184**A, and in which the BM resist **380** is in contact with the TFT substrate **17**, and the distance between the substrates is defined by both the BM protrusion **381** and the BM resist **380**. That is, the BM protrusion **381** and the BM resist **380** work as a spacer.

According to the 48th embodiment as described above, there is no need to pattern the BM simplifying the steps, and the BM works as a spacer eliminating the need of providing the spacer. In the 48th embodiment, the positive-type resist was used to form the BM by exposure to light through the back surface without effecting the patterning. However, either the negative-type resist or the positive-type resist can be used provided it can be patterned by the photolithography method. The resist which is not of a black color can be used for forming protrusion which works as a domain regulating means, or can be used as a spacer in compliance with the 47th embodiment.

Next, described below is a case where the protrusion **341** on which the CF resin is superposed in the 48th embodiment, is directly used as the BM.

FIGS. **185**A to **185**C are diagrams for illustrating the steps for producing the CF substrate according to a 49th embodiment, and FIG. **186** is a diagram illustrating a panel structure according to the 49th embodiment.

Referring to FIG. **185**A, the CF resin is superposed in three layers on the BM to form a protrusion **381** which permits light to pass through very little. Referring next to FIG. **185**B, the above-mentioned transparent flattening resin is applied by a spin coater maintaining a thickness of about 1.5 mm, post-baked at 230° C. for one hour and, then, an ITO film **12** is formed. Then, in FIG. **185**C, a positive-type resist (SC-1811 manufactured by Shipley Far East Co.) is applied maintaining a thickness of about 1.0 to 1.5 μm), pre-baked, and a protrusion **20**A is formed by the photolithography method. The protrusion **381** formed by superposing the CF resins B, G and R in three layers does not almost permit light to pass through and works as the BM. The thus completed CF substrate **16** and the TFT substrate **17** are stuck together via a spacer **45** to obtain a panel as shown in FIG. **186**.

The 47th to 49th embodiments have dealt with the cases where the BM was formed by superposing the CF resins. The liquid crystal display device of the VA system holding the negative-type liquid crystals, is normally black, and the non-pixel portions to where no voltage is applied do not almost permit light to pass through. Therefore, the BM for shielding light for the non-pixel portions may have a light transmission factor which is not acceptable in the case of the normally white device. That is, the BM may have a light transmission factor which is low to some extent. An 50th embodiment is to easily produce the CF substrate by giving attention to this point, and uses a CF resin or, concretely speaking, uses the resin B as the BM. This does not develop any problem from the standpoint of quality of display.

FIG. **187** is a diagram illustrating a step for producing the CF substrate according to the 50th embodiment, and FIGS. **188**A and **188**B are diagrams illustrating the panel structure according to the 50th embodiment.

Referring to FIG. **187**, the CF resins R, G (CR-7001, CG-7001, manufactured by Fuji Hanto Co.) of two colors are formed on the glass substrate **16**, and the negative-type photosensitive resin B (CB-7001 manufactured by Fuji Hanto Co.) is applied thereon by using a spin coater or a roll coater and is pre-baked. Then, the glass substrate **16** is exposed to ultraviolet rays of a wavelength of 365 nm in a dosage of 300 mJ/cm^2 from the back surface thereof, developed by using an alkali developing solution (CD manufactured by Fuji Hanto Co.), and is post-baked in an oven heated at 230° C. for one hour. Thereafter, an ITO film is formed and, then, a vertical alignment film is formed. That is, the resin B is formed on the portions other than the portions where the CF resins R and G are formed. The CF resins are not formed on the portions where the light must be shielded by forming the BM; i.e., the resin B is formed on the portions where the light must be shielded.

Referring to FIG. **188**A, the resin B **39**B is formed as BM on the portions of bus lines **31**, **32** and on the portions of TFTs where the light must be shielded. FIG. **188**B is a diagram illustrating, on an enlarged scale, a circular portion of a dotted line of FIG. **188**A. As shown, a high numerical aperture can be obtained by selecting the width of the light-shielding portion (resin B) **382** of the side of the CF indicated by an arrow to be equal to the widths of the bus lines **31**, **32** of the TFT substrate **17** to which a margin ① is added at the time of sticking the two pieces of substrates together.

In the 50th embodiment, the resin B is formed last since the transmission factors of the g-, h- and i-rays of photosensitive wavelengths are resin B>resin R>resin G. When the CF resin having a high exposure sensitivity (which may be exposed to a small amount of light) and the CF resin which permits photosensitizing wavelength to pass through at a large rate, are formed last, the resin of a color formed last remains little on the resins that have been formed already, which is desirable.

In general, it is effective if the first color is that of a resin (generally B>R>G in the transmission light) which makes it easy to discriminate the position alignment mark of an

exposure device, and if the alignment mark is formed together with the pixel pattern.

FIG. **192** is a diagram illustrating the structure of the CF substrate according to a 51th embodiment. In the conventional liquid crystal display device, the BM **34** of metal film is formed on the glass substrate **16**, the CF resin is formed thereon, and the ITO film is further formed thereon. According to the ninth embodiment, on the other hand, the BM is formed on the ITO film.

In the 51th embodiment, the CF resin **39** is formed by patterning on the glass substrate **16** like in the embodiments described above. As required, a transparent flattening member may be applied thereon. Next, a transparent ITO film **12** is formed, and a light-shielding film **383** is formed on a diagramed portion thereon. For example, the ITO film **12** is formed by sputtering maintaining a thickness of about 0.1 μm via a mask, and chromium is grown thereon as a light-shielding layer maintaining a thickness of about 0.1 μm. Furthermore, a resist is uniformly applied onto the light-shielding layer maintaining a thickness of about 1.5 μm by such a coating method as spin coating, and the light-shielding film is exposed to light through a pattern, developed, etched, and is peeled, thereby to form the light-shielding film **383**. The light-shielding film **383** is composed of chromium and is electrically conducting, has a large contact area relative to the ITO film **12** and makes it possible to lower the resistance of the ITO film **12** over the whole substrate. The ITO film **12** and the light-shielding film **383** may be formed by any method. According to the conventional method, the ITO film **12** is formed, and the substrate is annealed and is washed to form the chromium film. According to the 51th embodiment, the ITO film **12** and the chromium film are continuously formed in an apparatus, making it possible to decrease the step of washing and, hence, to simplify the steps. Therefore, no film-forming device is required, and the apparatus is realized in a small size.

FIGS. **190**A and **190**B are diagrams illustrating a modified example of the CF substrate of the 51th embodiment. In FIG. **190**A, the three CF resins are formed, another resin **384** is formed in a groove in the boundary of the CF resins, and the ITO film **12** and the light-shielding film **383** are formed. In FIG. **190**B, the two CF resins **39**R and **39**G are formed like in the eighth embodiment explained with reference to FIG. **187**. Then, the resin B is applied maintaining a thickness of about 1.5 μm, and the substrate is exposed to light from the back surface thereof and is developed to form a flat surface. Then, the ITO film **12** and the light-shielding film **383** are formed thereon. Since the surfaces of the CF layers are flat, the ITO film is not cut, and the resistance of the ITO film **12** can be lowered over the whole substrate.

When a colored resin having a low reflection factor is used as the resin **384** or **39**B under the light-shielding film **383**, the light-shielding portion exhibits a decreased reflection factor, and light falling on the liquid crystal display device from the outer side is less reflected. Furthermore, when a colored resin having a small transmission factor is used as the resin **384** or **39**B under the light-shielding film **383**, the light-shielding portion exhibits a decreased transmission factor, enabling the contrast of the liquid crystal display device to be enhanced.

In the structure of FIG. **190**B, furthermore, the CF resin **34**B is formed requiring no patterning. Therefore, there is no need to use an exposure apparatus which is capable of effecting the patterning and is expensive correspondingly, and the investment for the facilities can be decreased and the cost can be decreased, too.

FIG. **191** is a diagram illustrating a modified example of the 51st embodiment. Spacer for controlling the thickness of the liquid crystal layer are mixed in advance in the resist that is to be applied onto the light-shielding film. After the resist is patterned, therefore, the spacers **45** are formed on the light-shielding film that is formed in any shape. This eliminates the step for dispersing the spacers.

FIG. **192** is a diagram illustrating a CF substrate according to a 52rd embodiment. According to this embodiment, a chromium film is formed on the ITO film **12** and a resist is applied thereon. At the time when the light-shielding film **383** is to be patterned and exposed to light, the protrusion that works as a domain regulating means is patterned simultaneously therewith. After developing and etching, the resist is not peeled off but is allowed to stay. Thus, an insulating protrusion **387** that works as a domain regulating means is formed on the CF substrate **16**. By using such a CF substrate, there is realized a panel of a structure shown in FIG. **193**.

As described in the 47th embodiment, CF films are formed on a CF substrate, the CF substrate is coated with flatting resin such as acrylic resin so that the surface of the substrate becomes flat, and an electrode of an ITO film is formed thereon. In some cases, the surface flatting step is omitted in order to simplify the process. The CF substrate to which the surface flatting step is not performed is called a CF substrate with no top-coat. The CF substrate with no top-coat has grooves formed between respective CF films. The ITO film is formed with a sputtering process. When the ITO film is formed is formed on the CF substrate with no top-coat, it occurs a problem that the ITO layer is rigid on flat surfaces but it is coarse at the grooves because the sputtering process has anisotropy.

Therefore, when material of vertical alignment film is coated or printed, solvent included in the material infiltrates into the CF films through the grooves after the coating or printing to a precuring process. The infiltrated solvent remains inside the CF layers after the precuring process is completed. The solvent remained inside the CF films generates craters on the surfaces of the vertical alignment film. The craters cause display unevenesses. According to the 51th embodiment, the light-shielding film provided at the grooves can prevents the infiltration of solvent. In a 52th embodiment, resin provided at the grooves between respective CF films are used as protrusions.

FIGS. **251**A to **251**D are diagrams showing a production process of a CF substrate of the 52th embodiment. FIG. **251**A shows a CF substrate with no top-coat. The CF films **39**R, **39**G and **39**B are formed, the light-shielding films **34** are formed under the boundaries of the respective CF films, and the ITO film is formed the CF films. As shown in FIG. **251**B, a positive resist is coated. As shown in FIG. **251**C, the positive resist is irradiated with ultraviolet light from a surface of the glass substrate, and it is developed. Then, protrusions **390** are formed at positions corresponding to the light-shielding films **34**. The protrusions **390** prevent the infiltration of solvent. Further, the protrusions **390** operate as the protrusions **20**A of the CF substrate.

The structures of a liquid crystal display in accordance with the present invention have been described so far. Examples of applications of the liquid crystal display will be described below.

FIG. **194** shows an example of a product employing the liquid crystal display in accordance with the present invention, and FIG. **195** is a diagram showing the structure of the product. As shown in FIG. **195**, a liquid-crystal panel **100** has a display surface **111**, and makes it possible to view a

displayed image not only from the front side but also from any oblique direction defined by a large angle while offering an excellent viewing angle characteristic, a high contrast, and good quality but not causing gray-scale reversal. On the back side of the liquid crystal panel **100**, there are a light source **114** and a light box **113** for converting illumination light emanating from the light source **114** to light capable: of illuminating the liquid-crystal panel **100** uniformly.

As shown in FIG. **194**, a display screen **110** of this product is turnable and the product is therefore usable as either a sideways display or lengthwise display according to a purpose of use. A switch for use in detecting a tilt by 45° is therefore included. By detecting the state of the switch, switching is carried out to select whether display is carried out for the sideways display or for the lengthwise display. For this switching, a mechanism for changing a direction, in which display data is read from a frame memory for image display, by 90° is needed. The relevant technology is well-known. The description of the technology will be omitted.

An advantage provided when the liquid crystal display in accordance with the present invention is adapted to the above product will be described. Since a conventional liquid crystal display permits only a small viewing angle, when a large display screen is adopted, there arises a problem that a viewing angle relative to a marginal part of the screen gets so large that the marginal part becomes hard to see. However, a liquid crystal display in which the present invention is implemented makes it possible to view a high-contrast image even at a large viewing angle without occurrence of gray-scale reversal. In the product shown in FIG. **194**, a viewing angle relative to a longer marginal part of the display screen becomes large. It has therefore been impossible to adapt a liquid crystal display to this kind of product. The liquid crystal display of the present invention permitting a large viewing angle can be adapted to the product.

The aforesaid embodiments provide liquid crystal displays in each of which the orientation of a liquid crystal is divided for dividing each domain of the liquid crystal mainly into four regions whose azimuths are mutually different in increments of 90°, and liquid crystal displays in each of which the orientation of a liquid crystal is divided for dividing each domain of the liquid crystal mainly into two regions whose azimuths are mutually different in increments of 90°. This point will be discussed in relation to applications of the present invention. When the orientation of a liquid crystal is divided for dividing each domain of the liquid crystal into four regions whose azimuths are mutually different in increments of 90°, a good viewing angle characteristic can be exhibited in almost all directions. To whichever directions the orientation is set, no problem occurs in particular. For example, when the pattern of protrusions shown in FIG. **54** is arranged as shown in FIG. **196**A relative to a screen, a viewing angle at which display appears well is 80° or more both in lateral and vertical directions. Even after the screen is turned and the pattern of protrusions is arranged as illustrated on the right side of FIG. **196**A, no problem occurs in particular.

By contrast, when the orientation of a liquid crystal is divided for dividing each domain thereof into two regions whose azimuths are mutually different by 180°, the viewing angle characteristic will be improved relative to the directions into which the orientation is divided but will not be improved very much relative to directions different from the directions by 90°. When a nearly equal viewing angle characteristic is requested to be exhibited in both lateral and

vertical directions, a pattern of protrusions should preferably be, as shown in FIG. **196**B, run in an oblique direction in a screen.

Next, a process of manufacturing a liquid crystal display in accordance with the present invention will be described. In general, the process of manufacturing a liquid crystal panel comprises, as described in FIG. **197**, a step **501** of cleaning substrates, a step **502** of forming gate electrodes, a step **503** of forming an operating layer by applying a continuous film, a step **504** of separating devices, a step **505** of applying a protective film, a step **506** of forming pixel electrodes, and a step **508** of assembling components which are carried out in that order. For forming insulating protrusions, the step **506** of forming pixel elements is succeeded by a step **507** of forming protrusions.

As shown in FIG. **198**, the protrusion forming step comprises a step **511** of applying a resist, a step of pre-baking the applied resist, a step **513** of exposing a pattern of protrusions so as to leave the positions of the protrusions intact, a step **514** of performing development so as to remove portions other than the protrusions, and a step **515** of post-baking the remaining protrusions. As described above, at the subsequent step of applying an alignment film, there is a possibility that the resist may react upon the alignment film. At the post-baking step **515**, baking should therefore be carried out at a high temperature of a certain level. During the baking, if protrusions are curved to have a cylindrical section, the stability of alignment will increase.

Even when dents are formed as a domain regulating means, nearly the same process as the foregoing one is adopted. However, when electrodes are slitted, a pattern having slitted pixel electrodes should merely be created at the pixel electrode forming step **506** in FIG. **197**. The protrusion forming step **507** becomes unnecessary.

What is described in FIG. **198** is an example of drawing a pattern of protrusions using a photosensitive resist. The pattern of protrusions may be printed. FIG. **199** is a diagram showing a technique of drawing a pattern of protrusions by performing letterpress printing. As shown in FIG. **199**, a pattern of protrusions is drawn on a flexible relief plate **604** made of an APR resin. The relief plate is in turn fixed to the surface of a large roller **603** referred to as a plate cylinder. The plate cylinder is rotated while being interlocked with an anilox roller **605**, a doctor roller **606**, and a printing stage **602**. A polyimide resin solution used to form protrusions is dropped onto the anilox roller **605** by a dispenser **607**, and spread by the doctor roller **606** to be developed uniformly over the anilox roller **605**. The developed resin solution is transferred to the relief plate **604**. The solution transferred to the raised portion of the relief plate **604** is transferred to a substrate **609** on the printing stage **602**. Thereafter, baking or the like is carried out. Various techniques of drawing a microscopic pattern by printing have been employed in practice. If a pattern of protrusions can be drawn using any of the techniques, the pattern of protrusions can be drawn at low cost.

Next, injection of a liquid crystal into a liquid-crystal panel to be performed after upper and lower substrates are bonded will be described. As described in conjunction with FIGS. **18**A and **18**B, at the step of assembling components to produce a liquid-crystal panel, after a CF substrate and TFT substrates are bonded, a liquid crystal is injected. A VA type TFT LCD has cells whose thickness is small. It takes much time to inject a liquid crystal. Since protrusions are formed, it takes much more time to inject the liquid crystal. It is therefore requested to shorten the time required for injecting the liquid crystal as much as possible.

FIG. **200** is a diagram showing the configuration of a liquid-crystal injection apparatus. The details of the apparatus will be omitted. An injection connector **615** is attached to a liquid-crystal injection port of a liquid-crystal panel **100**, and a liquid crystal is supplied from a liquid-crystal defoamer and pressurizer tank **614'**. Concurrently, an exhaust connector **618** is connected to a liquid-crystal exhaust port, and the pressure in the liquid-crystal panel **100** is reduced using a vacuum pump **620** for deaeration so that a liquid crystal can be injected readily. A liquid crystal exhausted through the exhaust port is separated from an air by a liquid-crystal trap **619**.

In the first embodiment, as shown in FIGS. **18**A and **18**B, the protrusions **20** are linear and running in a direction parallel to the long side of the panel **100**. The liquid crystal injection port **102** is formed on a short side of the panel vertical to the protrusions **20**, while the exhaust ports **103** are formed on the other short side thereof opposite to the side on which the injection port **102** is formed. Likewise, as shown in FIGS. **201**A and **201**B, when the protrusions **20** are linear and running in a direction parallel to the short side of the panel **100**, preferably, the liquid-crystal injection port **102** is formed on one long side of the panel vertical to the protrusions **20**, and the exhaust ports **103** are formed on the other long side thereof opposite to the long side on which the injection port **102** is formed. Moreover, as shown in FIGS. **202**A and **202**B, when the protrusions **20** are zigzagged, the liquid-crystal injection port **102** is preferably formed on a side of the panel vertical to a direction in which the protrusions **20** are extending. As shown in FIGS. **203**A and **203**A, the exhaust ports **103** are preferably formed on a side of the panel opposite to the side on which the injection port **102** is formed.

During injection of a liquid crystal, foams may be mixed in the liquid crystal. Once foams are mixed in a liquid crystal, imperfect display ensues. Assuming that a negative liquid crystal and a vertical alignment film are employed, when no voltage is applied, black display appears. Even if foams are mixed in the liquid crystal, black display appears in areas coincident with the foams. The mixing of foams cannot therefore be discovered in this state. A voltage is applied to electrodes so that white display will appear. When black display does not appear in any area, it is confirmed that no foam has mixed in the liquid crystal. However, since there is no electrode near the liquid-crystal injection port, even if foams are mixed in a portion of the liquid crystal near the liquid-crystal injection port, the foams cannot be discovered. If foams are present in this portion of the liquid crystal, there is a fear that the foams will be dispersed to deteriorate display quality. Even the foams near the injection port must therefore be discovered. In a liquid crystal display of the present invention, therefore, as shown in FIG. **207**, an electrode **120** is formed near an injection port **101** outside a display area **121** and the black matrices **34** so that mixing of foams in this portion of a liquid crystal can be detected.

As explained above, the VA system liquid crystal display device using the domain regulating means such as the protrusion and the recess, the slit, etc, does not require the rubbing treatment. Therefore, contamination in the manufacturing process can be drastically reduced, and a part of the washing process can be omitted. However, the negative type (n type) liquid crystal used has lower contamination resistance to organic materials, particularly to polyurethane resin and the skin, than the positive type liquid crystal that is ordinarily used, and involves the problem that display defect occurs. This display defect presumably results from the drop, of the specific resistance of the contaminated liquid crystal.

Therefore, examinations are first made as to which size of the polyurethane resin and the skin causes this display defect. FIGS. **205**A to **205**C show the VA system liquid crystal panel. After the vertical alignment film is formed on the two substrates **16** and **17**, several polyurethane resins having a size of about 10 μm are put on one of the substrates. After the spacers **45** are formed on one of the substrates and the seal material **101**, on the other, the substrates are bonded to each other, and the panel is manufactured by charging the liquid crystal. As a result, it is found out that the polyurethane resin **700** expands to an area of 15 μm square by heat and by the formation of the cell thickness (cell gap), and the display defect due to contamination of the liquid crystal is recognized within the range of 0.5 to 2 mm with the polyurethane resin **700** as the center.

FIG. **206** shows the result of the investigation of the contamination area of the liquid crystal by changing the size of the polyurethane resin **700**. Assuming that no problem occurs when the display has a size of not greater than 0.3 mm square on the panel, the size of the polyurethane resin must be not greater than 5 μm. This also holds true of the skin.

As described above, the polyurethane resin and the skin lower the specific resistance of the liquid crystal, thereby inviting the display defect. Therefore, the relationship between the mixing quantity of the polyurethane resin and the drop of the specific resistance is examined. FIG. **207** shows the calculation result of frequency dependence of an equivalent circuit of the liquid crystal pixel shown in FIG. **208** by assuming the gate-on state. This graph shows the change of the effective voltage to the frequency when the resistance is 9.1×10^{9}, 9.1×10^{10}, 9.1×10^{11} and 9.1×10^{12} in the equivalent circuit of the liquid crystal pixel. It can be appreciated from the graph that the drop of the resistance value of the liquid crystal causes the drop of the effective voltage. It can be appreciated further that abnormal display occurs at the drop of the specific resistance of at least 3 digits within the frequency range of 1 to 60 Hz that is associated with the practical display.

FIGS. **208** and **209** are graphs showing within which time the charge once stored is discharged when the resistance is 9.1×10^{10}, 9.1×10^{11} and 9.1×10^{12}, respectively, by assuming the state where the liquid crystal pixel holds the charge. For reference, an example of the case where only the alignment film exists is shown, too. Because the alignment film has a large resistance and a large time constant, it hardly contributes to discharge phenomenon. FIG. **209** shows in magnification the portion below 0.2 s in FIG. **208**. It can be seen from this graph that when the liquid crystal resistance is lower by at least two digits, a black smear starts occurring at 60 Hz.

It can be understood from the observation described above that the problem develops when the resistance drops by two to three digits due to the polyurethane resin and the skin.

Next, after phenyl urethane is charged into the liquid crystal, a ultrasonic wave is applied for 10 seconds and the liquid crystal is thereafter left standing so as to measure the specific resistance of the supernatant. It is found out from the result that the specific resistance drops drastically when the mixing quantity of the polyurethane resin is about 1/1000 in terms of a molar ratio.

It is concluded from the explanation described above that non-uniform display does not occur at the level at which the

mixing quantity of the polyurethane and the skin is not greater than 1/1000 in terms of the molar ratio.

The embodiments of panels according to the present invention in which directions of alignment of liquid crystalline molecules are divided by the domain regulating means have been described so far. As already described, it is known that optical retardation film are available for improving the view angle performance. Next, embodiments regarding characteristics and arrangements of the retardation films will be described. The LCD panels of these embodiments have protrusions shown in FIG. **54**. Namely, in the VA LCD panel, the directions of alignment of liquid crystalline molecules are divided into four areas in each pixel.

FIG. **210** is a diagram showing a constitution of a prior art VA LCD. A space formed between two electroded **12**, **13** is sealed with a liquid crystal material. Thus a liquid crystal panel is completed. As shown in FIG. **210**, a first polarizing plate **11** and a second polarizing plate **15** are arranged at both sides of the panel. In the VA LCD, vertical alignment films are formed on the electrodes and the liquid crystal has negative dielectric constant anisotropy. The rubbing directions of the two vertical alignment films are different each other by 180 degrees. Further, the rubbing directions intersects with the absorption axis of the polarizing plates. Namely, the VA LVD panel is that shown in FIGS. **7**A to **7**C. FIG. **211** shows isocontrast curves. FIG. **212** shows viewing angle regions, in each of which gray-scale reversal occurs during an eight-gray-scale level driving operation in such a case. From these results, contrasts at directions of 0°, 90°, 180° and 270° are low and the gray-scale reversal occurs in wide view-angle.

FIG. **213** shows a constitution of a VA mode LCD device in which protrusion patterns as illustrated in FIG. **54** are formed.

FIG. **214** shows iso-contrast curves in the case of the LCD device shown in FIG. **213**. Further, FIG. **215** shows viewing angle regions, in each of which gray-scale reversal occurs during an eight-gray-scale-level driving operation, in the case of such a liquid crystal display device. These figures reveal that although the gray-scale reversal is improved in the case of this device as compared with the case of the conventional device of the VA (vertically aligned) type, the improvement on the gray-scale reversal is insufficient and that the contrast is not improved very much.

Applicant of the present application disclosed in Japanese Patent Application No. 8-41926/1996 and Japanese Patent Application Nos. 9-29455/1997 and 8-259872/1996, whose priority is based on the Japanese Patent Application No. 8-41926/1996 that the viewing angle characteristics of a liquid crystal display device of the VA type, on which the alignment division is performed by rubbing, are improved by providing an optical retardation film (namely, a phase difference film) therein. These Japanese Patent Applications, however, do not refer to the cases of performing the alignment division by protrusions, depressions (or dents) or slits respectively provided in pixel electrodes.

In the following, conditions for further improving the viewing angle characteristics of a liquid crystal display device of the VA type, which is adapted to perform the alignment division in each pixel through the use of protrusions, depressions or slits provided in the pixel electrodes, by providing an optical retardation film therein will be described.

First, the optical retardation film used in the device of the present invention will be described hereinbelow by referring to FIG. **216**. As illustrated in FIG. **216**, let n_x and n_y designate inplane refractive indices (or indices) respectively corresponding to inplane directions defined in a surface of the film. Further, let n_z denote a refractive index in the direction of thickness thereof. The following relation among the refractive indices n_x, n_y and n_z holds in the phase difference film to be used in the device of the present invention: $n_x, n_y \geqq n_z$.

Incidentally, an optical retardation film in which the following relation holds: $n_x \rangle n_y = n_z$, has optically positive uniaxiality therein. Hereunder, such a phase difference film will be referred to simply as a positive uniaxial film. Axis extending in a direction corresponding to a larger one of the inplane refractive indices n_x and n_y is referred to as a phase lag axis. In this case, $n_x \rangle n_y$. Therefore, the axis extending in the x-direction is referred to as the phase lag axis. Let d designate the thickness of the film. When light passes through this positive uniaxial film, the following phase difference (or optical retardation) R is caused in an inplane direction: $R=(n_x-n_y)d$. Hereinafter, the "phase difference caused by the positive uniaxial film" indicates a phase difference caused in an inplane direction.

Moreover, a phase difference film, in which the following relation holds: $n_x=n_y>n_z$, has optically negative uniaxiality in the direction of a normal to the surface thereof. Hereunder, such a phase difference film will be referred to simply as a negative uniaxial film. Let d designate the thickness of the film. When light passes through this negative uniaxial film, the following phase difference R is caused in the direction of the thickness thereof: $R=((n_x+n_y)/2-n_z)d$. Hereinafter, the "phase difference caused by the negative uniaxial film" indicates a phase difference caused in the direction of the thickness thereof.

Furthermore, a phase difference film, in which the following relation holds: $n_x \rangle n_y \rangle n_z$, has (optical) biaxiality. Hereunder, such a phase difference film will be referred to simply as a biaxial film. In this case, $n_x \rangle n_y$. Therefore, the axis extending in the x-direction is referred to as the phase lag axis. Let d designate the thickness of the film. When light passes through this positive uniaxial film, the following phase difference R is caused in an inplane direction: $R=(n_x-n_y)d$ (incidentally, $n_x \rangle n_y$). Further, the phase difference R caused in the direction of the thickness thereof is predetermined by the following equation:

$$R=((n_x+n_y)/2-n_z)d.$$

FIG. **217** is a diagram showing the constitution of a liquid crystal display device which is a 52th embodiment of the present invention.

Color filter and a common electrode (namely, what is called a full-surface covering electrode) are formed on the liquid-crystal-side surface of CF (Color Filter) substrate that is one of substrates **91** and **92**. Further, TFT elements, bus lines and pixel electrodes are formed on the liquid-crystal-side surface of TFT substrate that is the other of the substrates **91** and **92**.

Vertical alignment film is formed on the liquid-crystal-side surfaces of the substrates **91** and **92** by applying a vertical alignment material thereto through transfer printing, and by then burn the material at 180° C. Subsequently, a positive photosensitive overcoating (or protecting) material is applied onto the vertical alignment film through spin coating. Then, a protrusion pattern shown in FIG. **54** is formed by performing prebaking, exposure and postbaking.

The substrates **91** and **92** are bonded together through a spacer having a diameter of 3.5 μm. Further, a space formed

therebetween is sealed with a liquid crystal material having negative dielectric constant anisotropy. Thus a liquid crystal panel is completed.

As illustrated in FIG. **217**, the liquid crystal display device, which is the 52th embodiment of the present invention, is constituted by placing a first polarizing plate **11**, a first positive uniaxial film **94**, two substrates **91** and **92**, a second positive uniaxial film **94** and a second polarizing plate **15** therein in this order. Incidentally, the first and second uniaxial films **94** are placed so that the phase lag axis of the first positive uniaxial film **94** intersects with the absorption axis of the first polarizing plate **11** at right angles.

FIG. **218** shows iso-contrast curves in the case that each of the phase differences R_0 and R_1 respectively corresponding to the first and second positive uniaxial films **61** of the 52th embodiment is set at 110 nm. Further, FIG. **219** shows viewing angle regions, in each of which gray-scale inversion occurs during an eight-gray-scale-level driving operation in such a case. As is apparent from the comparison with FIGS. **214** and **215**, a range, in which high contrast is obtained, is enlarged extensively, with the result that the gray-scale reversal does not occur in the entire viewing angle region. Consequently, the viewing angle characteristics are considerably improved.

Incidentally, the viewing angle characteristics were studied by changing the retardation R_0 and R_1 in various ways in the case of the constitution of FIG. **217**. Process of studying the viewing angle was as follows. First, while changing the phase differences R_0 and R_1, an angle at which the contrast (ratio) was 10, was found in each of an upper right direction (corresponding to an azimuth angle of 45° towards the right top), an upper left direction (corresponding to an azimuth angle of 135° towards the left top), a lower left direction (corresponding to an azimuth angle of 225° towards the left bottom) and a lower right direction (corresponding to an azimuth angle of 315° towards the right bottom) with respect to the liquid crystal panel, as viewed in this figure. FIG. **220** is a contour graph showing each contour that connects points, each of which is represented by coordinates R_0 and R_1 thereof and corresponds to the found angle having a same value. Incidentally, the contour graphs respectively corresponding to the upper right direction, the upper left direction, the lower left direction and the lower right direction were the same with one another. It is considered that this was because four regions obtained by the alignment division were equivalent to one another as a result of using the protrusion pattern shown in FIG. **54**.

In the case of FIG. **217**, the angle, at which the contrast ratio is 10 in each of the directions respectively corresponding to the azimuth angles 45°, 135°, 225° and 315°, is 39°. This reveals that the use of the optical retardation film is effective in the case of the combination of the coordinates R_0 and R_1 shown in FIG. **223**. Incidentally, in the case illustrated in FIG. **223**, the angle, at which the contrast ratio is 10, is not less than 39° when R_0 and R_1 meet the following conditions or requirements:

$$R \leqq 450\ \mathrm{nm} - R_0,\ R_0 - 250\ \mathrm{nm} \leqq R_1 \leqq R_0 + 250\ \mathrm{nm},$$

$$0 \leqq R_0 \text{ and } 0 \leqq R_1.$$

Additionally, the retardation Δn·d caused in a liquid crystal was changed within a piratical range. Moreover, the twist angle was changed within a range of 0 to 90°. Similarly, the optimum conditions for R_0 and R_1 were obtained. As a result, it was ascertained that the optimum conditions were the same as the aforementioned requirements even in such cases.

FIG. **221** is a diagram showing the constitution of a liquid crystal display device which is a 53rd embodiment of the present invention. This embodiment is different from the 52nd embodiment in that two positive uniaxial films, namely, first and second positive uniaxial films **94** are placed between the first polarizing plate **11** and the liquid crystal panel, that the phase lag axes of the two positive uniaxial films **94** intersect with each other at right angles and that the phase lag axis of the second positive uniaxial film adjoining the first polarizing plate **11** intersects with the absorption axis of the first polarizing plate **11** at right angles.

FIG. **222** shows iso-contrast curves in the case that the phase differences R_0 and R_1 respectively corresponding to the first and second positive uniaxial films **61** of the 52nd embodiment are set at 110 nm and 270 nm, respectively. Further, FIG. **223** shows viewing angle regions, in each of which gray-scale inversion-occurs during an eight-gray-scale-level driving operation in such a case. As is obvious from the comparison with FIGS. **214** and **215**, a range, in which high contrast is obtained, is enlarged extensively. Moreover, the range, in which the gray-scale reversal occurs, is greatly reduced. Consequently, the viewing angle characteristics are considerably improved.

FIG. **224** shows the viewing angle characteristics obtained as a result of being studied by changing the phase differences R_0 and R_1 of the first and second uniaxial films **94** in various ways in the case of the constitution of FIG. **221**, similarly as in the case of the 52th embodiment. The viewing angle characteristics shown in FIG. **224** are the same as of FIG. **220** and are illustrated by a contour graph showing angles, at which the contrast ratio is 10, in terms of coordinates R_0 and R_1. As is seen therefrom, the angle, at which the contrast ratio is 10, is not less than 39° when R_0 and R_1 meet the following conditions or requirements:

$$2R_0 - 170\ \mathrm{nm} \leqq R_1 \leqq 2R_0 + 280\ \mathrm{nm},$$

$$R_1 \leqq -R_0/2 + 800\ \mathrm{nm},\ 0 \leqq R_0 \text{ and } 0 \leqq R_1.$$

Further, it was ascertained that the optimum conditions were the same as the aforementioned requirements even in the cases where, similarly, in the case of the 53th embodiment, the retardation Δn·d caused in a liquid crystal was changed within a practical range and where, moreover, the twist angle was changed within a range of 0 to 90°.

FIG. **225** is a diagram showing the constitution of a liquid crystal display device which is a 54th embodiment of the present invention.

This embodiment is different from the 52th embodiment in that the first negative uniaxial film **95** is placed between the liquid crystal panel and the first polarizing plate **11** and that the second negative uniaxial film **95** is placed between the liquid crystal panel and the second polarizing plate **15**.

FIG. **226** shows the viewing angle characteristics obtained as a result of being studied by changing the phase differences R_0 and R_1 in various ways in the case of the constitution of FIG. **225**, similarly as in the case of the 52th embodiment. The viewing angle characteristics shown in FIG. **226** are the same as of FIG. **220** and are illustrated by a contour graph showing angles, at which the contrast ratio is 10, in terms of coordinates R_0 and R_1. As is seen therefrom, the angle, at which the contrast ratio is 10, is not less than 39° when R_0 and R_1 meet the following condition or requirement:

$$R_0 + R_1 \leqq 500\ \mathrm{nm}.$$

Incidentally, similarly, in the case of the 54th embodiment, the retardation Δn·d caused in a liquid crystal and the

upper limit to the optimum condition were studied by changing the retardation Δn·d within a practical range. FIG. **227** illustrate results of this study. Let R_{LC} denote Δn·d caused in the liquid crystal. Consequently, the optimum value in the optimum condition for a sum of the phase differences respectively corresponding to the phase difference films is not more than $(1.7\times R_{LC}+50)$ nm.

Further, although this characteristic condition relates to the contrast (ratio), the optimum condition for the gray-scale reversal was similarly studied. Angles, at which gray-scale reversal occurs, were found by changing the phase differences R_0 and R_1 in the direction of the thickness of the first and second negative uniaxial films **95** in various manners in the constitution of FIG. **225**, similarly as in the case of the contrast ratio. FIG. **228** shows contour graphs obtained from the found angles, which is illustrated by using the coordinates R_0 and R_1. Incidentally, the angle, at which the gray-scale reversal occurs in the case illustrated in FIG. **215**, is 52°. Thus, when the phase differences R_0 and R_1 have values at which the angle enabling an occurrence of the gray-scale reversal is not less than 52° in the case illustrated in FIG. **228**, the phase difference film has an effect on the gray-scale reversal. In the case shown in FIG. **228**, the angle, at which the contrast ratio is 10, is not less than 39° when R_0 and R_1 meet the following condition or requirement:

$$R_0+R_1 \leqq 345 \text{ nm.}$$

Then, in the case of the 54th embodiment, the relation between Δn·d caused in a liquid crystal (display) cell and the upper limit to the optimum condition was studied by changing the retardation Δn·d within a practical range. FIG. **229** illustrate results of this study. This reveals that the upper limit to the optimal condition is nearly constant independent of Δn·d caused in the liquid crystal cell and that the optimum condition for a sum of the phase differences respectively corresponding to the phase difference films is not more than 350 nm.

It is desirable that the angle, at which the contrast ratio is not less than 50°. Further, in view of the gray-scale reversal and Δn·d caused in the liquid crystal cell, it is preferable that a sum of the phase differences respectively corresponding to the phase difference films is not less than 30 nm but is not more than 270 nm.

Moreover, as a result of studying the optimal condition by changing the twist angle in a range of 0 to 90°, it is found that the optimum condition was the same as the aforementioned requirement.

A 55th embodiment of the present invention is obtained by removing one of the first and second negative uniaxial films **95** from the constitution of the liquid crystal display device of FIG. **225**, which is the third embodiment of the present invention.

FIG. **230** shows iso-contrast curves in the case that the phase difference corresponding to one of the negative uniaxial films **95** of the 55th embodiment is set at 200 nm. Further, FIG. **231** shows viewing angle regions, in each of which gray-scale inversion occurs during an eight-gray-scale-level driving operation in such a case. As is obvious from the comparison with FIGS. **214** and **215**, a range, in which high contrast is obtained, is enlarged extensively. Moreover, the range, in which the gray-scale reversal occurs, is greatly reduced. Consequently, the viewing angle characteristics are considerably improved. Moreover, the optimal condition for realizing the contrast ratio of 10 and the optimal condition for the gray-scale reversal were studied. Results of this study reveal that it is sufficient to use a single negative uniaxial film having the phase difference corresponding to a sum of the phase differences of the negative uniaxial films of the 54th embodiment.

Each of 56th to 58th embodiments of the present invention uses the combination of positive and negative uniaxial films. Although there are various kinds of modifications to the arrangement of such films, it has been found that the constitutions of the fifth to seventh embodiments have (advantageous) effects.

FIG. **232** is a diagram showing the constitution of a liquid crystal display device which is a 56th embodiment of the present invention.

The 56th embodiment differs from the 52th embodiment in that a negative uniaxial film **95** is used and placed between the liquid crystal panel and the first polarizing plate **11** instead of the first positive uniaxial film **94**.

FIG. **233** shows iso-contrast curves in the case that the phase difference R_0 in an inplane direction in the surface of the positive uniaxial film **94** and the phase difference R_1 in the direction of thickness of the negative uniaxial film **95** are set at 150 nm in the 56th embodiment. Further, FIG. **234** shows viewing angle regions, in each of which gray-scale inversion occurs during an eight-gray-scale-level driving operation in such a case. As is obvious from the comparison with FIGS. **214** and **215**, a range, in which high contrast is obtained, is enlarged extensively. Moreover, the range, in which the gray-scale reversal occurs, is greatly reduced. Consequently, the viewing angle characteristics are considerably improved.

In the case of the 56th embodiment, the optimal condition for the contrast was studied. FIG. **235** shows results of this study, which reveal that the optimum condition indicated by FIG. **235** was the same as illustrated in FIG. **220**.

FIG. **236** is a diagram showing the constitution of a liquid crystal display device which is a 57th embodiment of the present invention. This embodiment is different from the 52th embodiment in that a positive uniaxial films **61** are placed between the liquid crystal panel and the first polarizing plate **11** and that a negative uniaxial film **95** is placed between this positive uniaxial film **94** and the first polarizing plate **11**. The positive uniaxial film **94** is placed in such a manner that the phase lag axis thereof intersects with the absorption axis of the first polarizing plate **11** at right angles.

FIG. **237** shows iso-contrast curves in the case that the phase difference R_0 in an inplane direction in the surface of the positive uniaxial film **61** and the phase difference R_1 in the direction of thickness of the negative uniaxial film **62** are set at 50 nm and 150 nm in the 57th embodiment, respectively. Further, FIG. **238** shows viewing angle regions, in each of which gray-scale inversion occurs during an eight-gray-scale-level driving operation in such a case. As is obvious from the comparison with FIGS. **214** and **215**, a range, in which high contrast is obtained, is enlarged extensively. Moreover, the range, in which the gray-scale reversal occurs, is greatly reduced. Consequently, the viewing angle characteristics are considerably improved.

Even in the case of the 57th embodiment, the optimal condition for the contrast was studied. FIG. **239** shows results of this study, which reveal that the optimum condition indicated by FIG. **239** was the same as illustrated in FIG. **220**.

FIG. **240** is a diagram showing the constitution of a liquid crystal display device which is a 58th embodiment of the present invention. This embodiment is different from the 52th embodiment in that a negative uniaxial films **95** are placed between the liquid crystal panel and the first polarizing plate **11** and that a positive uniaxial film **94** is placed between this negative uniaxial film **95** and the first polariz-

ing plate **11**. The positive uniaxial film **94** is placed in such a manner that the phase lag axis thereof intersects with the absorption axis of the first polarizing plate **11** at right angles.

FIG. **241** shows iso-contrast curves in the case that the phase difference R_1 in an inplane direction in the surface of the positive uniaxial film **94** and the phase difference R_0 in the direction of thickness of the negative uniaxial film **95** are set at 150 nm in the 58th embodiment. Further, FIG. **242** shows viewing angle regions, in each of which gray-scale inversion occurs during an eight-gray-scale-level driving operation in such a case. As is obvious from the comparison with FIGS. **214** and **215**, a range, in which high contrast is obtained, is enlarged extensively. Moreover, the range, in which the gray-scale reversal occurs, is greatly reduced. Consequently, the viewing angle characteristics are considerably improved.

Even in the case of the 58th embodiment, the optimal condition for the contrast was studied. FIG. **243** shows results of this study, which reveal that the optimum condition indicated by FIG. **243** was the same as illustrated in FIG. **220**.

FIG. **244** is a diagram showing the constitution of a liquid crystal display device which is an 59th embodiment of the present invention.

This embodiment is different from the 52nd embodiment in that a phase difference film **96**, whose inplane dielectric constants n_x and n_y and dielectric constant n_z in the direction of thickness thereof have the following relation: n_x, $n_y \geqq n_z$, is placed between the liquid crystal panel and the first polarizing plate **11** and that a positive uniaxial film **94** is removed from between the liquid crystal panel and the second polarizing plate **15**. The phase difference film **96** is placed in such a manner that the x-axis thereof intersect with the absorption axis of the first polarizing plate **11** at right angles.

FIG. **245** shows iso-contrast curves in the case that the x-axis is employed as the phase lag axis of the phase difference film **96**, namely, $n_x \rangle n_y$ and that the phase difference in an inplane direction in the surface of the film and the phase difference in the direction of thickness thereof are set at 55 nm and 190 nm, respectively, in the 59th embodiment. Further, FIG. **246** shows viewing angle regions, in each of which gray-scale inversion occurs during an eight-gray-scale-level driving operation in such a case. As is obvious from the comparison with FIGS. **214** and **215**, a range, in which high contrast is obtained, is enlarged extensively. Moreover, the range, in which the gray-scale reversal occurs, is greatly reduced. Consequently, the viewing angle characteristics are considerably improved.

Incidentally, quantities R_{xy} and R_{yz} are defined as follows: $R_{xy}=(n_x-n_y)d$; and $R_{yz}=(n_y-n_z)d$. In the case of the 59th embodiment, the optimal condition for the contrast (ratio) was studied by changing the quantities R_{xy} and R_{yz} in various ways. FIG. **247** shows the found optimal condition for the contrast. The optimum condition shown in FIG. **247** was the same as the aforementioned condition (of FIG. **220**), except that R_0 and R_1 correspond to R_{xy} and R_{yz}, respectively. These results reveal that the angles, at which the contrast ratio is 10, are not less than 39° when the quantities R_{xy} and R_{yz} satisfy the following conditions:

$$R_{xz}-250\ \text{nm} \leqq R_{yz} \leqq R_{xz}+150\ \text{nm},$$

$$R_{yz} \leqq -R_{xz}+1000\ \text{nm},$$

$$0 \leqq R_{yz} \text{ and } 0 \leqq R_{xz}.$$

Incidentally, let R_0 and R_1 denote the phase difference in an inplane direction of the phase difference film **96** and the phase difference in the direction of thickness thereof, respectively. Thus, the following relations hold for these phase differences:

$$R_0=(n_x-n_y)d=R_{xz}-R_{yz} \ldots \text{ (in the case that } n_x \geqq n_y);$$

$$R_0=(n_y-n_x)d=R_{yz}-R_{xz} \ldots \text{ (in the case that } n_y \geqq n_x);$$

and

$$R_{yz}=((n_x+n_y)/2-n_z)d=(R_{xz}-R_{yz})/2.$$

Therefore, the optimal conditions for R_{xz} and R_{yz} are written as follows:

$$R_0 \leqq 250\ \text{nm},\ R_1 \leqq 500\ \text{nm}.$$

Namely, it is desirable that the inplane phase difference is not more than 250 nm and the phase difference in the direction of thickness of the film is not more than 500 nm and that the biaxial phase difference film is placed so that the phase lag axis thereof intersects with the absorption axis of the adjacent polarizing plate at right angles.

As a result of studying the relation between the retardation Δn·d caused in a liquid crystal cell and the upper limit to the optimal condition by changing the retardation Δn·d in various way within a practical range, it was found that the optimal condition for the phase difference in an inplane direction was not more than 250 nm regardless of the retardation Δn·d caused in a liquid crystal cell. In contrast, the phase difference in the direction of thickness depends on the retardation Δn·d caused in a liquid crystal cell. FIG. **248** shows the results of the study on the relation between the retardation Δn·d caused in a liquid crystal cell and the upper limit to the optimal range of the phase difference in the direction of thickness of the film. Let R_{LC} denote Δn·d caused in the liquid crystal. Consequently, it is concluded that the optimum value in the optimal condition for the phase difference in the direction of thickness of the phase difference film is not more than $(1.7 \times R_{LC}+50)$ nm.

Incidentally, the optimal condition in the case of a configuration, in which a plurality of phase difference films **96** were placed in at least one of spaces formed between the liquid crystal panel and one of the first polarizing plate **11** and the second polarizing plate **15**, which were provided at one or both of sides of the liquid crystal panel, and between the liquid crystal panel and the other thereof was studied similarly. As a result, it was found that the optimum condition was the case where the phase difference in the inplane direction of each of the phase difference films **96** was not more than 250 nm and that a sum of the phase differences in the direction of thickness of the phase difference films **96** was not more than $(1.7 \times R_{LC}+50)$ nm.

Further, as a result of studying the optimal condition similarly by changing the twist angle in a range of 0 to 90°, it was found that the optimum condition was the same as the aforementioned requirement.

A positive uniaxial film $(n_x \rangle n_y = n_z)$, a negative uniaxial film $(n_x = n_y \rangle n_z)$ and a biaxial film $(n_x \rangle n_y \rangle n_z)$ are employed as the film **96**. Namely, a single or a combination of such films may be used.

In the foregoing description, there has been described the optimal conditions for the phase difference film in the case that alignment division is performed in a pixel by providing rows of protrusions on the liquid-crystal-side of each of the two substrates composing the liquid crystal panel. However, even in the case of performing the alignment division by

using depressions or slits formed in the pixel electrodes, the viewing angle characteristics can be improved on the similar conditions.

Further, in the present specification, the polarizing plates have been described as ideal ones. Therefore, it is obvious that the phase difference (incidentally, the phase difference in the direction of thickness of the film is usually about 50 nm) caused by a film (namely, TAC (cellulose triacetate) film) protecting a polarizer should be synthesized with the phase difference caused by the phase difference film of the present invention.

Namely, the provision of the phase difference film may be omitted apparently by making TAC film meet the conditions according to the present invention. However, in this case, needless to say, such TAC film performs as well as the phase difference film of the present invention, which should be added to the device, does.

The embodiments in which the present invention is implemented in a TFT liquid crystal display have been described. The present invention can also be implemented in liquid crystal displays of other types. For example, the present invention can be implemented in a MOSFET LCD of a reflection type but not of the TFT type or in a mode using a diode such as a MIM device as an active device. Moreover, the present invention can be implemented in both a TFT mode using an amorphous silicon and a TFT mode using a polycrystalline silicon. Furthermore, the present invention can be implemented in not only a transmission type LCD but also a reflection type or plasma-addressing type LCD.

An existing TN LCD has a problem that it can cover only a narrow range of viewing angles. An IPS LCD exhibiting an improved viewing angle characteristic has problems that a response speed it can offer is not high enough and it cannot therefore be used to display a motion picture. Implementation of the present invention can solve these problems, and realize an LCD exhibiting the same viewing angle characteristic as the IPS LCD and offering a high response speed surpassing the one offered by the TN LCD. Moreover, the LCD can be realized merely by forming protrusions on substrates or slitting electrodes, and can therefore be manufactured readily. Besides, the rubbing step and after-rubbing cleaning step which are required for manufacturing the existing TN LCD and IPS LCD become unnecessary. Since these steps cause imperfect alignment, an effect of improving a yield and product reliability can also be exerted.

Since the LCD offering a high operating speed and exhibiting a good viewing angle characteristic can be realized, expansion of an application range including the application to a monitor substituting for the CRT is expected.

What is claimed is:

1. A liquid crystal display device, comprising:

a first substrate and a second substrate for sandwiching a liquid crystal having a negative dielectric constant anisotropy, and molecules of the liquid crystal aligning in a direction vertical to the first and second substrates when no voltage is applied,

said first substrate including first domain regulating means for regulating azimuths of orientations of said liquid crystal molecules when a voltage is applied to said liquid crystal, said azimuths of orientations being defined as alignments of respective ones of said molecules in a horizontal plane generally parallel to planes of the first and second substrates, and

said second substrate including second domain regulating means for also regulating said azimuths of the orientations of said liquid crystal molecules when a voltage is applied to said liquid crystal,

wherein when vertically seen to the substrates, said first domain regulating means includes first line portions and second line portions, said first line portions being extended in a first direction, said second line portions being extended in a second direction different from said first direction, said second domain regulating means includes third line portions and fourth line portions, said third line portions being extended in said first direction, said fourth line portions being extended in said second direction, said first and third line portions being arranged to be neighbored and to be approximately parallel to each other, and said second and fourth line portions being arranged to be neighbored and to be approximately parallel to each other, and

wherein said azimuths of the orientations are regulated according to respective directions of said line portions.

2. A liquid crystal display device according to claim **1**, said first and second domain regulating means includes protrusions, depressions, slits, or combinations thereof.

3. A liquid crystal display device according to claim **2**, wherein at least four kinds of domains, in which said azimuths of the orientations of said liquid crystal are substantially different, are formed when a voltage is applied to said liquid crystal.

4. A liquid crystal display device according to claim **3**, wherein a difference angle between said first and second directions is about 90 degrees.

5. A liquid crystal display device according to claim **3**, wherein said first and second directions differ from edges of pixel electrodes by about 45 degrees.

6. A liquid crystal display device according to claim **1**, wherein said line portions of said first and second domain regulating means are repeatedly arranged with a predetermined pitch respectively on said first and second substrates.

7. A liquid crystal display device according to claim **6**, wherein said first and second domain regulating means are offset by half of said predetermined pitch.

8. A liquid crystal display device according to claim **1**, wherein said line portions of said first and second domain regulating means are bent in a generally zigzag shape.

9. The liquid crystal display device according to claim **1**, wherein said first and second line portions are physically connected.

10. The liquid crystal display device according to claim **1**, wherein said first and second line portions are not physically connected.

11. The liquid crystal display device according to claim **1**, wherein said third and fourth line portions are physically connected.

12. The liquid crystal display device according to claim **1**, wherein said third and fourth line portions are not physically connected.

13. A liquid crystal display device comprising:

a first substrate and a second substrate for sandwiching a liquid crystal having a negative dielectric constant anisotropy, and molecules of the liquid crystal aligning in a direction vertical to the first and second substrates when no voltage is applied,

said first substrate including first domain regulating means for regulating azimuths of the orientations of said liquid crystal when a voltage is applied to said liquid crystal, said azimuths of orientations being defined as alignments of respective ones of said molecules in a horizontal plane generally parallel to planes of the first and second substrates, and

said second substrate including second domain regulating means for also regulating said azimuths of the orientations of said liquid crystal when a voltage is applied to said liquid crystal,

wherein when vertically seen to the substrates, said first domain regulating means includes first line portions and second line portions, said first line portions being extended in a first direction, said second line portions being extended in a second direction different from said first direction, said second domain regulating means includes third line portions and fourth line portions, said third line portions being extended in said first directions, said fourth line portions being extended in said second direction, said first and third line portions being arranged to be neighbored and to be approximately parallel to each other, said second and fourth line portions being arranged to be neighbored and to be approximately parallel to each other, and all of said first, second, third, and fourth line portions existing within each of a plurality of pixels, and

wherein said azimuths of the orientations are regulated according to respective directions of said line portions.

14. A liquid crystal display device according to claim **13**, wherein said line portions of said first and second domain regulating means are arranged with a predetermined pitch respectively on said first and second substrates.

15. A liquid crystal display device according to claim **14**, wherein said predetermined pitch is an integral submultiple of said arranged pitch of said pixels.

16. A liquid crystal display device according to claim **14**, wherein said line portions of said first and second domain regulating means are bent in a generally zigzag shape.

17. A liquid crystal display device according to claim **14**, wherein said line portions of said first and second domain regulating means are offset by half of said predetermined pitch.

18. A liquid crystal display devices comprising:

a first substrate and a second substrate for sandwiching a liquid crystal having a negative dielectric constant anisotropy, and molecules of the liquid crystal aligning in a direction vertical to the first and second substrates when no voltage is applied,

said first substrate including first domain regulating means for regulating azimuths of the orientations of said liquid crystal when a voltage is applied to said liquid crystal, said azimuths of orientations being defined as alignments of respective ones of said molecules in a horizontal plane generally parallel to planes of the first and second substrates, and

said second substrate including second domain regulating means for also regulating said azimuths of the orientations of said liquid crystal when a voltage is applied to said liquid crystal,

wherein, when vertically seen to the substrates, said first domain regulating means includes first line portions being extended in a first direction, said second domain regulating means includes second line portions being extended in a second direction, said first line portions being arranged to be approximately parallel to each other at a predetermined pitch and second line portions being arranged to be approximately parallel to each other at said predetermined pitch, and said first and second line portions being crossed, and

wherein said azimuths of the orientations are regulated according to respective directions of said line portions.

19. A liquid crystal display device according to claim **18**, wherein when vertically seen to the substrates, said first domain regulating means further includes third line portions being extended in said second direction, said second domain regulating means further includes fourth line portions being extended in said first direction, said third portions being arranged to be approximately parallel to each other, said fourth line portions being arranged to be approximately parallel to each other, and said third and fourth line portions being crossed.

20. A liquid crystal display device according to claim **19**, wherein when vertically seen to the substrates, said first, second, third, and fourth line portions respectively being extended continuously, said first and third line portions being crossed to form quadrangles, said second and fourth line portions being crossed to form quadrangles, and said quadrangles formed by said first and third line portions and said second and fourth line portions being offset.

21. A liquid crystal display device according to claim **20**, wherein when vertically seen to the substrates, said arrangement offset of said quadrangles is a half of said predetermined pitch.

22. A liquid crystal display device according to claim **20**, wherein when vertically seen to the substrates, said first direction and said second direction cross at right angles.

23. A liquid crystal display device, comprising:

a first substrate having an inner surface and an outer surface;

a first electrode on the inner surface of the first substrate;

a first protrusion on the inner surface of the first Substrate,

wherein the first protrusion is shaped as a bent line in plane view;

a second substrate opposite the first substrate and having an inner surface and an outer surface;

a second electrode having boundaries on the inner surface of the second substrate in plane view; and

a second protrusion on the inner surface of the second substrate,

wherein the second protrusion is shaped as a bent line in plane view,

whereby the first protrusion and the second protrusion have saw shapes in plane view, and

wherein the first protrusion and the second protrusion are arranged alternatively in plane view.

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